UNIVERSITY OF LEICESTER

UKSEDS

UK STUDENTS FOR THE EXPLORATION AND DEVELOPMENT OF SPACE

Proceedings of

SSEA

3rd Symposium on Space Educational Activities

University of Leicester

16-18 September 2019

Image: The Helix Nebula in the Infra Red. Image Credit: ESO/VISTA/J. Emerson

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NATIONAL SPACE ACADEMY

Proceedings of the
3rd Symposium on Space Educational Activities

16th – 18th September 2019
University of Leicester, UK

Organised by

University of Leicester

UK Students for the Exploration & Development of Space

National Space Academy

ESA Education Office

Editors

Nigel Bannister
Áine O'Brien
Alexander Kinnaird

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Preface

The 3rd Symposium on Space Educational Activities (3rd SSEA) was hosted at the University of Leicester, UK, from 16th – 18th September 2019. The event represented the continuation of a successful programme which began at the University of Padova, Italy in 2015, followed by the 2nd Symposium hosted by the Budapest University of Technology and Economics, Hungary, in 2018.

In common with the previous events, the 3rd SSEA provided an international stage for students, academics and representatives of space agencies and the space industry to discuss current and future space educational activities in Europe and beyond. More than seventy oral presentations and posters covered space educational activities at university level, as well as opportunities for learners and educators in high school. Talks at the 3rd SSEA showcased student projects, some involving real missions in which students were involved in designing, building and operating spacecraft; the use of ground and airborne facilities (such as drop towers and parabolic flights) in space education; technologies for training the next generation of space engineers and scientists; how universities and employers can work together so that graduates have the skills needed by industry, and the challenges faced by women and under-represented groups seeking to enter, or already working in, the field. Keynote talks were presented by Dr Maggie Liu ("Working in the space industry as a woman and a minority") and Dr Suzie Imber ("Adventures in Space"). The Symposium included an evening lecture open to members of the public as well as conference delegates: the talk was given by author and TV presenter Dallas Campbell, who captivated the audience with a presentation on "How to make a spacesuit" – bringing his own replica of Neil Armstrong's A7L Apollo space suit).

Top Left: Aine O'Brien (left) & Jess Goldie (right) demonstrating a liquid nitrogen-cooled superconductivity levitation experiment at the welcome reception.. Bottom Left: Dallas Campbell presenting the Symposium public lecture, with his replica of Neil Armstrong's Apollo spacesuit. Right: The ESA Academy team underneath the National Space Centre's Soyuz module during the Symposium dinner. (L-R: Alex Kinnaird, Natacha Callens, Esther Susana Rufat Meix, Piero Galeone).

Symposium Organisation

The Symposium was organised by the University of Leicester in partnership with the National Space Academy, and UKSEDS (UK Students for the Exploration and Development of Space), and the ESA Education Office.

The University of Leicester has a long and distinguished history of involvement in space science, with a presence in space unbroken since 1967. It has held, and continues to hold, major roles in missions for agencies including ESA, NASA, ISRO and JAXA, covering astronomical, planetary, and Earth observation science missions including ESA's XMM-Newton, EuMetSat and BepiColombo missions, and the joint NASA – ESA James Webb Space Telescope. Its research includes X-ray and observational astrophysics, radio and space plasma physics, planetary science, instrumentation, and the development of new radioisotope power systems for space exploration. Our education and training programme includes undergraduate and postgraduate degrees with strong space science themes, and opportunities for students to work with researchers and the international space industry.

The National Space Academy (NSA) is a not-for-profit organisation which engages young people with Science, Technology, Engineering and Maths subjects using the inspirational context of space, facilitating pathways into the sector by working with industry and education. It teaches high school and college students, trains teachers, and works with industry and academia to develop the next generation of space science talent. Over 55,000 students and 6000 teachers have participated in NSA masterclasses and training programmes in the UK and overseas since 2008 and NSA is a lead organisation in the UK's Government's strategic programme of collaboration in space science with China. The NSA's main office is located in Leicester's National Space Centre (NSC), a major visitor centre and educational resource covering space science, space research and astronomy. The NSC houses real rockets, space exhibits and interactive displays, along with the UK's largest full dome planetarium.

The University of Leicester and National Space Academy are partners in Space Park Leicester – a project to create a major hub for space and space-enabled industry. Development and delivery of education and training for the space sector is a key objective of the venture, and the Symposium represented the first education and training event for Space Park Leicester.

UKSEDS is the UK's national student space society. For over 30 years UKSEDS has supported students and young professionals across the country by running events, providing resources, and teaching them new skills. UKSEDS alumni work throughout the global space sector in government, industry, and academia. At events and in schools all over the UK, UKSEDS volunteers inspire and educate children and the public, building support for space, and online our careers resource, SpaceCareers.uk, is the number one website of its kind, serving hundreds of visitors every day. UKSEDS' substantial contributions to the event included programme organisation, hosting of the Symposium's web site and registration system, and provision of UKSEDS team members to run sessions.

The ESA Education Office is responsible for the Agency's corporate education programme bringing together young people from many different nations. The aim is to help young Europeans, aged from 6 upwards, to gain and maintain an interest in science and technology, with the long term objectives of contributing towards the creation of a knowledge-based society and ensuring the existence of a qualified workforce for the agency that will secure Europe's continued leadership in space activities.

Organizing Committee

Nigel Bannister (University of Leicester):	Co-Chair
Aine O'Brien (UKSEDS):	Co-Chair + Diversity & Inclusion
Anu Ojha (National Space Academy):	Co-Chair
Kierann Shah (National Space Academy):	NSA Representative & D&I
Joseph Dudley (UKSEDS):	Publicity & Web Management
Anne Edwards (University of Leicester):	Organisational Support
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Alexander Kinnaird (ESA):	ESA Education Office
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Sabrina Corpino – Politecnico di Torino
Piero Galeone – ESA Education Office
Robert Garner – UKSEDS/UKSA
Suzie Imber – University of Leicester
Alexander Kinnaird – ESA Education Office
Tom Lyons – ESERO-UK
Aine O'Brien – UKSEDS/University of Glasgow
Anu Ojha – National Space Academy
Lorenzo Olivieri – University of Padova
Mervyn Roy – University of Leicester
Kierann Shah – National Space Academy
Nicole Viola – Politecnico di Torino
Hugo Williams – University of Leicester

Student Volunteers

The organisers wanted students to benefit from all aspects of the symposium, not only through presenting and listening to talks, but by providing opportunities to develop other skills. Most of the sessions in the symposium were chaired by students from the institutes participating in the Symposium, and throughout the event, volunteers from UKSEDS and University of Leicester's Astronomy and Rocket Society ensured smooth running of the sessions and support for delegates. We thank the following students for their help:

Jessica Goldie (UKSEDS / University of Leicester)
Rachael Dixon (UKSEDS / University of Edinburgh)
Joshua Ford (UKSEDS / University of Leicester)
Hannah Biddle (University of Leicester)
Laura Martin (UKSEDS / Liverpool John Moores University)
Lilli Helps (UKSEDS / University of Leicester)
Jacob Smith (UKSEDS / Cranfield University)
Briani Reynolds (University of Leicester)

Supporting Organisations

We are grateful to the UK Space Agency (UKSA), ESERO-UK, and the Royal Astronomical Society for providing support for the event.

The UK Space Agency (UKSA) is an executive agency of the Department for Business, Energy & Industrial Strategy, responsible for all strategic decisions on the UK civil space programme and providing a clear, single voice for UK space ambitions. UKSA is leading UK civil space policy and increasing the UK's engagement with global initiatives. It is building a strong national space capability, including scientific and industrial centres of excellence and co-ordinating strategic investment across industry and academia. UKSA is working to inspire and train a growing, skilled UK workforce of space technologists and scientists for the whole space sector.

The UK Space Education and Resource Office (ESERO-UK) helps teachers use the context of space to open doors for young people aged 4 to 19, by delivering engaging, world-class teaching in STEM. ESERO-UK have recently started a programme with UKSEDS, called Student Space Ambassadors, train to students who want to work as STEM Ambassadors, volunteering their enthusiasm and time with young people to help bring STEM subjects to life and demonstrate their value in life and careers. ESERO-UK offers high impact CPD to teachers, both online and face-to-face. This high quality training and support is based on the latest developments in education and research. ESERO-UK's CPD is supported by an online library of over 700 free, space-related resources available to educators across the UK. These resources are chosen for their high quality and relevance for the national curriculum. They are produced by organisations including ESERO-UK, Royal Society of Chemistry, ESA, Royal Observatory Greenwich and the National Space Academy. We are based in the National STEM Learning Centre in York. Working alongside STEM Learning Ltd, ESERO-UK is able to provide influence, funding and services to improve the teaching of STEM subjects in schools and colleges, and inspire young people through engagement and enrichment activities.

The Royal Astronomical Society (RAS), founded in 1820, represents UK astronomy nationally and internationally, encouraging and promoting the study of astronomy, solar-system science, geophysics and closely related branches of science. Its more than 4,000 members (Fellows), a quarter based overseas, consists of primarily professional astronomers and geophysicists, with a significant number of students, advanced amateurs, as well as historians of astronomy and geophysics. The RAS Organizes scientific meetings and events throughout the country, publishes international research and review journals, recognizes outstanding achievements by the award of medals and prizes, and supports education through grants and outreach activities.

3rd SSEA Symposium Delegation
Stamford Court, Leicester, 16th September 2019

Contents

Music therapy for human spaceflights: psycho-physiological responses of musical stimulus under hypergravity stressors

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Abstract—Music has been historically reported in spaceflights as inducing on astronauts positive psychological and physiological effects in a similar manner to Guided Imagery, a technique often used by professionals in multiple settings such as sports, to reduce stress and anxiety, and improve focus prior to or during an activity, Listening to music has also been reported by trained spaceflight crews during their pressurization checks of the vehicle prior to launch. Once launched they encounter hypergravity conditions that put physiological and psychological stress upon the body, however, it is not documented the effect of this practice of listening to music acts to reduces stress. With commercial spaceflight tourism on the horizon, where a wider population will be exposed to these larger hypergravity stresses for longer periods of time, the potential for non-invasive countermeasures to reduce possible stress would be advantageous. The aim of this study was to understand if music could be used during hypergravity stress to induce a positive psychological state and reduce markers of physiological stress. The experiment was kindly supported by the European Space Agency (ESA) Education Office and the German Aerospace Center (DLR) as part of the ESA Spin your Thesis – Human Edition 2018.

Keywords—human spaceflight; music therapy; hypergravity

I. INTRODUCTION AND METHODS

According to the established experiment's protocol on the Short Arm Human Centrifuge (SAHC) at DLR, we based on the principles of The Bonny Method (GIM) used in Guided Imagery using music selection as a stimulus instead of an image. Music was devised for use during a controlled hypergravity environment of 1Gz and 1.5Gz. Questionnaires were applied on the selection aiming to approach the subject's musical and psycho-cultural profile. 11 subjects volunteered for the study and were split into two groups according to their music styles affinity (with music [n=6] and without music [n=5]. Psychological POMS tests and physiological markers including muscles tone (MyoTone Pro), galvanic skin resistance and stress hormones cortisol/cortisone measurements were performed before, during, after each centrifuge and compared between groups. According to the music period, harmonic, rhythmical character/ density and subjects preferences, two music samples were selected, edited and played separately on each centrifuge for 5 minutes. The first music sample a documentary soundtrack and the second music sample a slow movement (adagio molto e cantabile) from a classical symphony, both samples written in the key of B flat major containing harmonic modulation sequences from the classical, romantic and xx. century musical periods, including strings acoustic instrumentation in the classic orchestral formation and electronic instruments/effects.

Muscles	Pre	After 1G	After 1.5G	Pre	After 1G	After 1.5G
	Control group without music			Music group		
Biceps Brachii Long	14.67	15.52	15.18	13.54	14.28	14.125
Masseter	14.9 ± 1.06	15.44 ± 1.07	15.83 ± 1.30 (p=0.13 NS)	14.31± 1.48	14.19 ± 0.74	14.26 ± 0.83
Rectus Femoris	15.62±0.86	16.2 ± 0.66 (p=0.07)	16.01	15.35	15.78* (1G vs Pre, p<0.05)	15.89
Rectus Abdominis	14.69	14.94	15.11	12.43	13.26	12.84
Sternocleidomastoid	13.7	12.53	12.54	13.26	12.5	12.53
Tibialis Anterior	22.97	21.05	21.31	22.37	19.1	19.05

Figure 1: Comparison of muscle properties in the control group (n=5 ; without music) to the music group (n=6 ; in green). Oscillation Frequency (in Hertz), before (Pre) after 1G and after 1.5G Mean +/- SEM, each value is the mean of left and right sides per subject. Significant P value when *p<0.05.

II. RESULTS

Psychological POMS (profile of mood states) tests and music pleasantness questionnaires results in the Music group participants showed a pleasantness tendency to prefer slower rhythmic and lower rhythmical density music such as the slow classical symphony movement. After the two centrifuges, music pleasantness questionnaire revealed that 2/5 preferred the

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documentary soundtrack and 4/5 preferred the classical slow movement. One of the subjects has remarked to strongly unlike the slow classical's composer on the pre-centrifuge questionnaires, curiously, the subject has found pleasant both samples after the centrifuge. The music group has decreased psychological tension levels from "43" points before the spin to "18" points after the spin marking a decrease of 25 points in comparison with the control group with "33" points before the spin and "23" after the spin marking a decrease of 10 points. Only the control group without music have included a subject who has increased psychological tension after the two centrifuges. Muscle tone (Myoton pro) results in music group have sown especially in the masseter muscle a tendency to decrease after the musical intervention. The masseter was physically the closest measured muscle to the music stimuli. According to the other two participating teams protocol, after each music sample, the subjects performed 5 minutes of squats exercises that may have influenced the results. Subjects that experienced hypergravity with music were less stressful or a least without significant differences in tension points and showed a tendency to decrease the stress. Galvanic skin resistance and hormonal tests are currently under treatment due to their complexity and data amount.

III. CONCLUSIONS

Hypergravity and music have affected all the psychological and physiological parameters. Music has decreased the stress feeling in this extreme environment, however, further experiments could provide significant outcomes statistically. It is proposed to test music intervention adapted to parabolic flights (hypergravity vs. microgravity), analog simulations or under permanent microgravity. Further studies may consider to include a wider historical musical selection for a longer time and the psycho-physiological measurements of instrumental practice. The continuation of music research in space could conduct to select music periods/styles that are specifically useful to control mood states, avoid sleep disorders, extend/improve mental and physical performance on astronauts. In long-term spaceflight music therapy could be one of the most important psycho-physiological countermeasures.

IV. ACKNOWLEDGMENT

Special Thanks to Nigel Savage, Programme Coordinator for University Student Experiments at the ESA Education Office, to Loïc , Endorsed Professor for all his support in physiology, hardware travel organization. Thanks to Timo Frett, Guido and Alexandra Noppe from DLR- facility for their flexibility to adapt the subject's recruitment and the centrifuge audio/sound hardware for this music experiment.Thanks to Tamás Nagy and the Hungarian Academy of Sciences (TTK) coordinating in advance travel/accommodation for Spanish/Hungarian team members and thanks to CNES grant for sub-collaborating with the galvanic skin device and travel/accommodation for French team members. Special thanks to the European Low Gravity Research Association supporting this first endeavor with music therapy for human spaceflights.

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Fly a Rocket Campaign! A Unique ESA Academy Hands-on Project

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***Abstract*— The *Fly a Rocket! Campaign* is an ESA hands-on project in collaboration with the Norwegian Space Agency and the Norwegian Center for Space-related Education (NAROM) which allows university students at their first or second year of Bachelor degree to build, launch and operate their own first sounding rocket from the Andoya Space Centre located in Northern Norway. This paper gives a general overview of the second edition of this programme, as it took place throughout winter 2018 – spring 2019. Being selected to be member of the *Telemetry and Data Readout team*, the author's task was to set up and operate the telemetry station, including manually tracking the rocket and downloading its data, making sure that the students received and collected data from the rocket. For this reason, this paper will focus particularly on the activities followed by the Telemetry and Data Readout team members.**

Keywords*— *sounding rocket; education; Andoya; ALOMAR

I. Introduction

The project was designed to offer University students early in their studies the chance to learn about rocketry and launch their own rocket from Andoya Space Center.

Through their participation in the programme, students were meant to gain experience in how to:

- Reproduce a scientific project: scientific objective, building and testing instrumentation, retrieve telemetry data, analysis, and conclusions;
- Work on a real rocket project as a team and interact with industry experts and other students from several different nations.

Students taking part in the *Fly a Rocket! Campaign* also learn about:

- How a rocket engine works using solid, liquid or hybrid propulsion technology;
- Basic rocket theory – be able to derive the rocket equation;
- Rocket aerodynamics and stability – the physics behind a sounding rocket and know the forces acting on a rocket;
- The use of rockets, balloons and ground based instruments as a technology platform to study processes in the atmosphere;
- Sensors and basic electronics;
- Orbital mechanics and use of satellite navigation.

II. The Rocket

The student rocket is a version of the Mongoose 98 optimized for didactic purposes. The Mongoose 98 has a length of 2.708 metres and a width of 102.8 mm. It is mostly made of carbon and glass fiber. Its total weight is 18.762 kg, of which:

- 1.3 kg is payload;
- 4.812 kg is the Pro98-N2501-P Cesaroni solid propellant motor, which burns for 6.09 seconds, giving an average thrust of 2,501.8 N;
- 8.496 kg is solid propellant;
- 4.154 kg is the dry weight of the rocket.

An electronic plate is mounted along the elongated axis, and on this plate the encoder, the transmitter, 2 S-band antennas, the battery and the sensors are mounted.

The suite of instruments flown on the rocket included an external and internal temperature sensors, a pressure sensor, a magnetometer, a two-axis accelerometer, a light sensor, a GPSIMU for latitude, longitude, altitude, velocity and three axis acceleration, an array mounted on the inside of the nosecone, counting 10 different temperature sensors.

III. Teams Overview

The 23 students involved in the project were split into four different working teams, each composed by an appropriate number of people, with different and peculiar tasks.

A. Telemetry and Data Readout

The Telemetry and Data Readout team was in charge of preparing the Student Telemetry Station (NAROM TM) to receive, visualize and record sensor and housekeeping data transmitted from the Student Rocket.

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The team worked both on the hardware and the software part of the Telemetry Station. The hardware part was composed by:

a. A horn antenna;

b. Two receivers;

c. A combiner, which took the best signal from the receivers;

d. A bit-synchronizer, which reduced the noise;

e. The decoder.

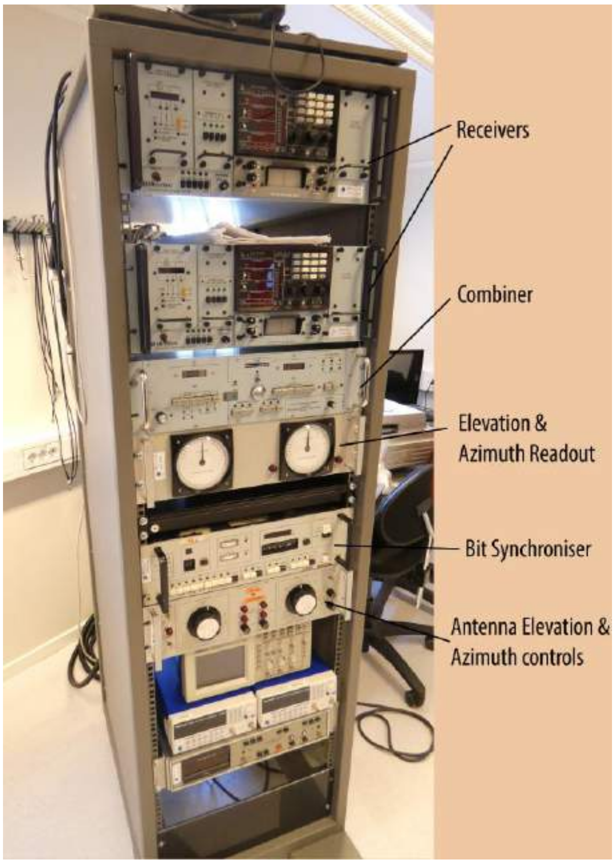

Figure 1. NAROM Telemetry Tower

While the software used were Matlab, to export data collected into format suitable for plotting, and DEWESoft, to tell the telemetry station what data were of interest and how it should have arranged them in displays. This was also the phase of more overlapping between groups: the Payload and Sensor teams members shared with the Telemetry team the equations to implement in DEWESoft. Those equations represented the calibration of the sensors, thus related the voltage sampled by the instrument to the physical value measured during the flight.

The group also operated the Student Telemetry Station and assisted the operations of the Main Telemetry Station (a second telemetry station which the students where just in charge of operating, not building), according to the Countdown Procedure handed out at the Pre-flight meeting.

In addition to this, the team studied how they could measure the slant range using phase shift, measured with a phasemeter. Which is to say, how is it possible to exploit doppler effect due to the movement of the rocket in respect with the ground station to measure the length of the trajectory flown.

B. *GPS and Simulations*

The GPS and Simulations team was responsible for building the GPS sensor and running simulations including the rocket's trajectory and the position of the Centre of Gravity and the Centre of Pressure.

C. *Payload*

The Payload team accounted for the final assembly of the rocket's payload. Additionally, the Payload team built the umbilical (for power and transmission at the launchpad), assembled the wiring for the encoder and transmitter boards, and built two of the temperature sensors.

D. *Sensors experiments*

The Sensor team made all the sensors (except the two of the Payload team). In addition, they prepared and launched two weather balloon PTU probes prior to the rocket launch.

IV. PRE-COURSE

Before the launch campaign, the students were expected to complete two individual assignments. In order to do so, they had been strongly recommended to attend the online course offered by NAROM. The pre-course taught the students about:

- Rocket engines: the rocket principle, the rocket equation, total impulse, the nozzle, rocket motor efficiency, the engine types (solid, liquid, hybrid, ion thruster);Basic rocket theory – be able to derive the rocket equation;
- Rocket dynamics: aerodynamics and forces acting on the rocket, simulating a rocket launch;
- Satellite orbits: Kepler's laws, six basic orbital parameters, orbit equations in a plane, examples of orbits.

Those assignments, especially the second one, were challenging on purpose, as to promote cooperation between the participants through online platforms.

V. LAUNCH CAMPAIGN

The launch campaign took place at the Andoya Space Center, one of the most popular facilities worldwide for sounding rockets and aerostatic balloons, with an illustrious history, counting over 1,200 sounding and sub-orbital rocket launches in its 57-year lifespan.

The students stayed at the Space Centre from the 7th to the 13th of April 2019.

Day 1 – travel day, welcome and practical information; Day 2 – introductions, rocketry lectures, tour of the Andoya Space Center, start of the student rocket work; Day 3 – lectures on balloons and radiosondes, continue

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working on the rocket, MATLAB lecture;
Day 4 – payload testing, whale museum;
Day 5 – presentation of data from simulations, pre-flight briefing and safety brief, rocket operation, post-flight meeting, evaluate data, prepare for presentation, Gala dinner;
Day 6 – presentations of data collected;
Day 7 – travel day.

A. Lectures

During the week in Andoya, the students attended a number of lectures, given by experts, regarding technical aspects such as rocket physics, transmitting data, balloons, radiosondes and ALOMAR Observatory but also some others aimed at raising students' consciousness of how wide the spectrum of Space activities is, for instance how is like to work at an operative rocket range, or to be an operator in Kourou (French Guiana).

Most of the lectures were in common for all the teams. Some of them were specifically shaped for tasks peculiar of each team.

B. Labs work

The teams worked on their tasks in near rooms so that they could interact when they had to. The labs work on the rocket started the day after the students arrived at Andoya. Each of the four groups was followed by one or more NAROM experts.

A key factor characterizing the labs work was the attitude "The students take the work": they were really pushed to work on the rocket, make it ready to fly with all the sensors working and being able to have data back on the ground. The students believed that all was their responsibility, even though the technicians from NAROM tended to correct their mistakes without giving the feeling that the rocket would have flown because they oversaw the students' activities.

C. The day before the launch

The day before the launch, the students used NAROM telemetry station to verify the health of the payload, in order to be sure that each sensor was working and they received data from it. It was a critical moment, since some issues occurred with the temperature sensors on the nose of the rocket, but eventually, checking each connection, the Sensors team solved the problem.

D. Launch day

Before the launch, the students attended a safety brief in which Andoya experts explained in detail all safety matters.

The launch was at first one hour delayed due to a plane transit above the launch area.

All the students were provided with a countdown procedure, nominally 1 hour long. As a matter of fact, the countdown stopped at minus 15 minutes because the telemetry stations didn't receive data from the payload, while the rocket was at the launchpad.

The reason was that the rocket experienced connection issues with the umbilical cords. The problem took half an hour to be solved, by removing the rocket from the umbilical cords, restarting the power system and attaching the rocket to the cords again.

E. PTU sondes

Prior to the rocket launch, the students launched two PTU sondes (aerostatic balloons with pressure-temperature-humidity sensors) to verify the weather conditions were good enough to go for the rocket launch.

F. The excursions

During the week in Andoya, the students could take part into several exciting excursions:

1) The whale museum;
2) The lighthouse;
3) The near city of Andenes.

They could also use their spare time to go hiking to the mountains surrounding the Space Centre.

G. Post flight analysis

The data collected thanks to telemetry (the rocket was not recovered) were immediately worked by the students. Each of them was given a particular case study, which related two aspects of the flight, for instance altitude vs velocity, battery vs temperature, light vs altitude and so on.

The rocket reached an altitude of almost 8 km, a maximum velocity of 2.0 Mach, and a peak in the acceleration in the travelling direction of 17g.

After the first moments, in which the rocket spun on its axis many times per second, the rocket spin reached its minimum soon after apogee.

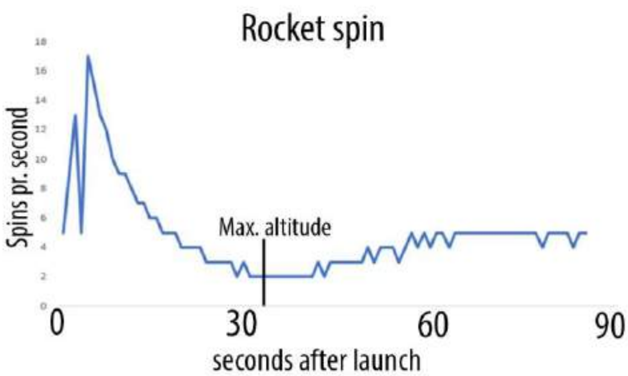

Figure 2. Spin vs time

The case study the Telemetry Team was expected to analyse was the difference in signal received by NAROM Telemetry station (the one set up by the students) and, instead, the MAIN Telemetry station (the one the students just operated). The outcome was that more powerful antennas

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locking automatically on the rocket (MAIN Telemetry station) are able to maintain a more stable telemetry link than smaller, manually pointed ones (NAROM Telemetry station).

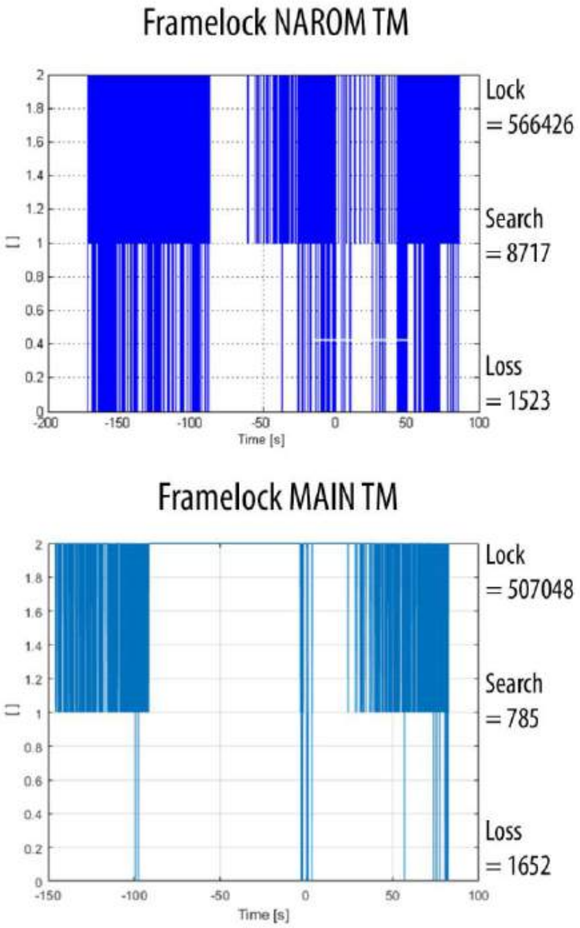

Figure 3. Telemetry case study

Indirectly, thanks to the light sensor but also the study of the launch video frame by frame, the students found the clouds to be at an altitude of 1100m.

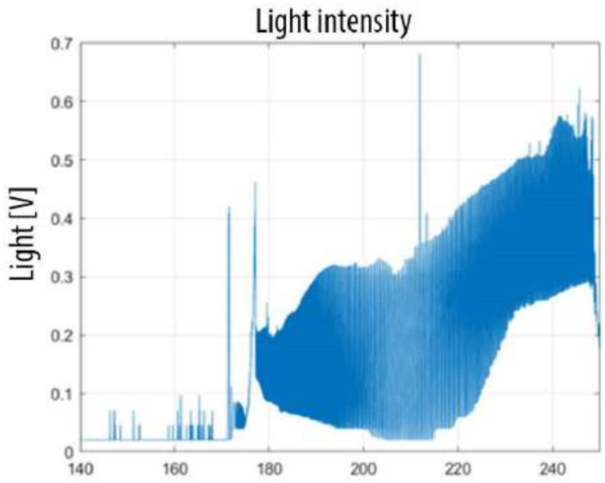

Figure 4. Light vs time

Drag calculations allowed to derive the drag coefficient of the rocket, which was obtained to be 0.7.

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Exoplanets at School – an educational program about hunting and analyzing exoplanets – meets the FREI-project

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***Abstract*— Since 2015, pupils (secondary level, grades 7-10) are able to conduct analogy experiments to explore at the school laboratory of the University of Cologne how to detect and analyze exoplanets. The experiments deal with various methods for the search for exoplanets (transit-method, direct imaging and astrometry), spectral analysis, the temperature of a star and the habitable zone, the greenhouse effect, the atmospheric pressure, the albedo, the influence of the solar wind and ultraviolet radiation on the probability of the existence of life. The experience gained has led to a continuous development of the experiments and the entire project, e.g by taking into account preconceptions of the pupils. In particular, the experiment about the transit-method was revised in the so-called FREI-project. The FREI-project is a remote-controlled laboratory (RCL) which allows to perform various physics experiments via the Internet. As a consequence, the exoplanet experiment – located at the University of Cologne – can be integrated into regular lessons by teachers around the world, since live streams and light curves are transmitted over the Internet. This article gives a brief overview of the individual experiments at the school laboratory and the experiences gained. In addition, the extension of the original transit-method experiment in the student laboratory to a FREI-experiment is described.**

Keywords—exoplanets, analogy experiments, transit method, FREI-project, physics teaching

I. Introduction

Physics is not a very popular subject at school in Germany and most of the pupils – especially girls – are not interested in the contents specified in the curriculum [1, 2]. In response to this fact, physics education in Germany should be context-oriented [3]. The results of the Relevance of Science Education (RSE) study [2] show that female and male pupils are usually interested in different contexts: For example, only boys are interested in “technical contexts”, while girls are much more interested in “Body and Health” [2]. If physics education wants to become more suitable for both boys and girls, it has to take into account the interests of both sexes. As the ROSE study [2] shows, the context “The possibility of life outside earth” is the most popular one for girls and boys. In order to motivate both girls and boys for physics, this context should be explicitly included in the school-lessons. How this can succeed, the authors of this article examine in a first step in the school laboratory “Our Spacecraft Earth” at the University of Cologne.

II. The Exoplanet Project at the School Laboratory “Our Spacecraft Earth”

In 2015, the first version of the exoplanet project for the school laboratory was developed [4,5]. In this project, pupils come to the university for a day to conduct analogy experiments on finding and examining exoplanets. In particular, the state variables density, composition of the atmosphere and the temperature at the exoplanet are considered in more detail. In order to determine the density, information about the radius and the mass of the exoplanet is needed. Information about the radius is obtained from the transit method [6]. An upper limit for the mass is obtained from the radial-velocity method [6] which has been added in an improved version of the original project.

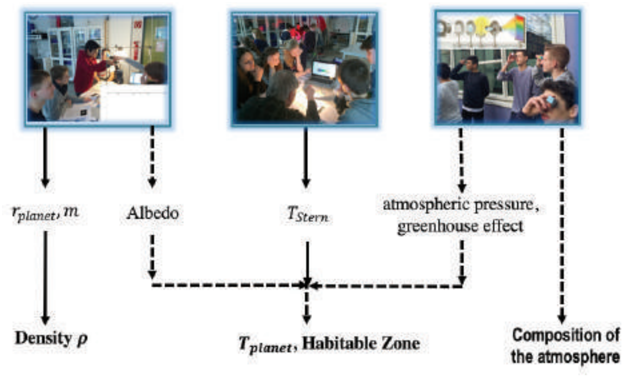

Fig. 1: Important state variables of exoplanets.

The composition of the exoplanets’ atmosphere can be measured by the spectrum of the star within the primary and secondary transit [6].

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The location of the habitable zone is particularly influenced by the temperature of the star and the distance between the exoplanet and the star. Furthermore, the temperature at the exoplanet is influenced by the albedo of the planet, the atmospheric pressure and the greenhouse effect [6]. The temperature of the star can be determined by observations, for example from the spectrum and Wien's displacement law. The albedo results from the light curve which is measured by the transit method [8]. An experiment on the albedo has not been part of the first version of the project.
In addition to this other experiments deal with dangerous radiation like the solar wind and ultraviolet-radiation.
This article focusses on the transit method. Further information about the other experiments can be found in [4,5].

III. The Transit-Method in an Analogy-Experiment

When an exoplanet moves around the star, it temporarily covers a portion of the star for an observer on earth. By measuring the intensity of the star over time, many exoplanets have already been discovered [7].

A. The first version of the experiment

The aim of the experiment is the development of the transit method by the pupils. In addition, the pupils should test the method in an analogy experiment. As especially the development of the method is not easy, the pupils are supported by a bachelor-student. The setup of the experiment is shown in figure 2.

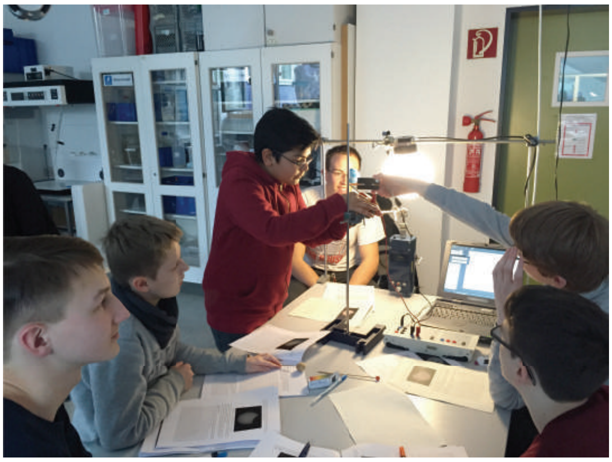

Fig. 2: Setup of the first version.

A motor is used to move a ball – the "exoplanet" – around a lamp – the "star". The intensity of the "star" can be measured with a solar cell. Using a computer program, the voltage generated by the solar cell can be plotted against time. The experiment is limited by the fact, that pupils get to know the transit method but not the limits of the method. Therefore a second version of the experiment has been developed.

B. The second version of the experiment

As part of a seminar at the University of Cologne, the setup of the transit experiment has been expaned by students of the University of Cologne and the authors of this article. The reason for this expansion was the desire to show the pupils that not every exoplanet can be detected with the transit method. Therefore a second lamp was added to the setup (compare figure 3).

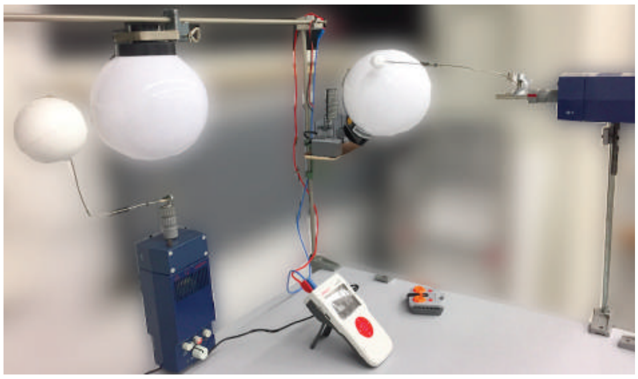

Fig. 3: Setup of the second version.

The intensity is measured by a solar cell, which can be directed by a motor on the respective lamp. The difference between these two „stars“ in the inclination of the „exoplanet“. While the „exoplanet“ of „star“ A (left lamp in figure 2) moves between „star“ and solar cell, the „exoplanet“ of „star B“ (right lamp in figure 2) has an inclination of 90° and it does not darken the lamp from the solar cell's point of view. The experimental setup allows to compare the lightcurves of both situations (see figure 4 and 5).

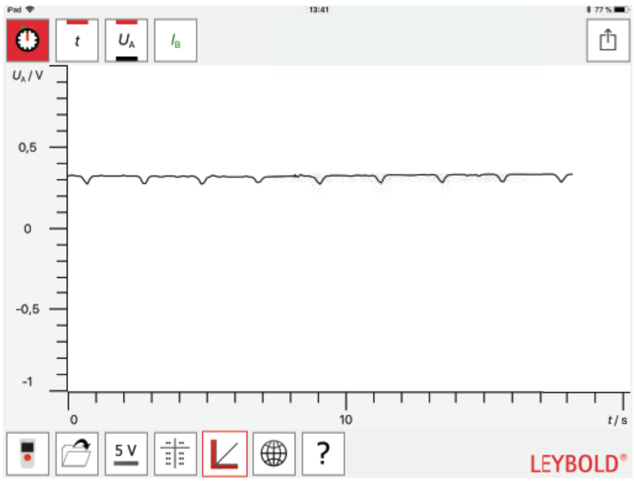

Fig. 4: Light curve of "star" A measured with CASSY Lab by LD Didactic.

Compared to the first version, the pupils do not see the structure of the second version at the beginning of the experiment, as this setup is placed in a different room. They only get information from the measured light curves. Typically, the pupils say that there is only an "exoplanet" moving around "star" A, as the intensity gets lower at regular intervals. At the next step a cognitive conflict is used when the pupils go to the room where the experiment is located and see that both "stars" have an "exoplanet" moving around it. Furthermore, they are

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able to observe why the “exoplanet” of “star B” can’t be detected with the transit method. The current setup has some advantages over the old construction, like the possibility to understand the limits of the method.

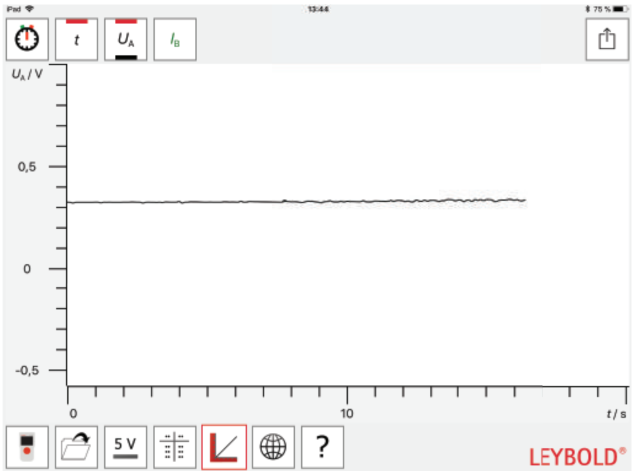

Fig. 5: Light curve of “star” B measured with CASSY Lab by LD Didactic.

A disadvantage is that a supervisor has to move the solar cell to generate the cognitive conflict. As a result of this, a third version has been developed as a FREI-experiment.

IV. The FREI-Project

A. General information about the FREI-project

FREI is an abbreviation for “**F**ernsteuerung von **r**ealen **E**xperimenten über das **I**nternet” [Remote control of real experiments via the Internet]. The project was developed at the Institute of Physics at the University of Applied Sciences Cologne (TH Cologne) as a way of giving rising numbers of Bachelor-students in Engineering the opportunity to perform a decent number of experiments in practical-work-classes, while reducing the time and manpower needed at the same time [10]. [11]. Remote-controlled experiments have a good learning effect when the experiment does not require a hands-on approach [10]. More technical details specifically for a remotely-controlled forced mechanic oscillation experiment can be found in [11].

The FREI-experiments can be controlled via the Internet. The user needs to register and log in to the FREI-Website www.frei-web-th-koeln.de. Afterwards the user can join one of the setup courses with a password to get access to the experiments required for the practical-work-class and book a timeslot to perform the experiment. In this time the user gains exclusive access to a website that contains the input controls and output data of the chosen experiment. Many experiments also provide live data from a webcam.

The user’s inputs are sent to a server that checks the request and forwards it to the lab-computer at the TH Cologne. There the data is used by a LabView-VI to set the required parameters in the experiment or perform certain actions. Furthermore, the website can request measurements in the same way. The measurement data is recorded by digital multimeters which the LabView-VI can read out directly. All those steps are necessary to make sure that no input sent by a student leads to an error in the controlling VI. Also, it prevents the student from having direct access to the computer at the TH Cologne.

For an experiment to be built for the FREI-project it needs to have an actor for any adjustment you want to set and a sensor for any data you want to get. The controlling VI needs to be accessible via the Internet all day with a fixed IP address so that the server can route data between the website and the lab-computer.

B. The third version of the transit-experiment as a FREI-experiment

The analogy-experiment for the transit-method is especially suited for remote control [9]. The pupils are not supposed to see the set-up before the measurements are completed and they have made a presumption if there is a “planet” orbiting the “star”. Only after that they are supposed to control their guess.

For this reason, the third version of the transit experiment is built in three boxes. Each box contains a diffuse spherical lamp that is orbited by a plastic ball using an electro-motor. A solar panel is placed on the wall of the box to provide data for the lamp’s intensity. The webcam is positioned directly next to the solar panel so that the image transmitted to the website is synchronized with the data gained by the solar panel.

The trajectories of the “planets” on “stars” 1 and 2 both have no inclination from the observer’s perspective, but the setups are different regarding their scale. “Starsystem” 2 is 1.5


Fig. 6: Third version of the transit method-experiment.


Fig. 7: Central controlling unit.

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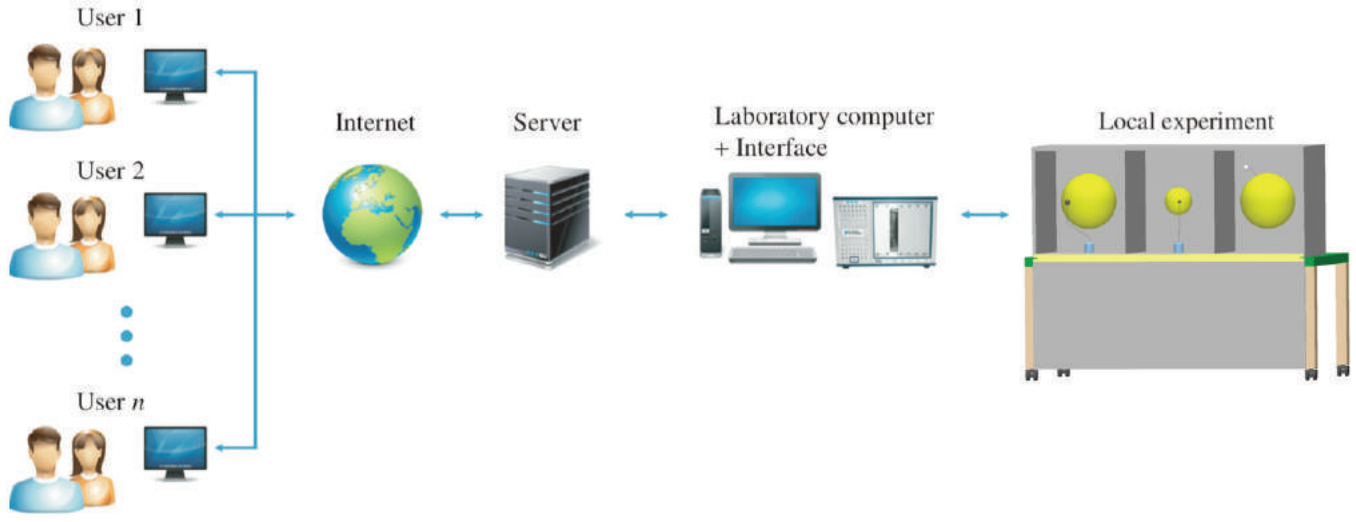

Fig. 8: Functional principle of the Exoplanet-FREI-Experiment. Reproduced and modified from [10] with permission.

times bigger than “starsystem” 1. The difference can be seen in the intensity graph by a lower dip during the transit in system 2. The inclination on “star” 3 is 90°. This is achieved by placing the observing units (solar panel and webcam) on the lid of the box.

To activate the correct inputs and output, a LabView-VI sends requests to a Central Controlling Unit (CCU) via USB. This unit contains three driver modules – one for each of the motors – which can be accessed by the driver module’s software via USB. The lamps’ and the solar panels’ circuits are broken by a relay so that they can be activated on the switch of the maker. Each relay’s maker is therefore connected to one of the driver module’s outputs. At last the output of the CCU is connected to the digital multimeter that is linked to LabView (compare Fig. 8).

On the FREI website the pupils can choose one of the three “stars” to direct their “telescope” at. After starting the measurement, a diagram visualizes the intensity data. After stopping the measurement, the users are able to activate the webcam and thereby look directly at the set-up.

In contrast to the first two versions of the experiment the pupils’ perspective is limited to the webcam’s point of view. Because of that it is easier for them to understand why the “planet” orbiting “star” 3 can’t be found using the transit-method. On the other hand, the pupils don’t see the set-up with their own eyes if the experiment is performed via the internet. They also do not have the opportunity to touch it or point at certain things.

First experiences with the third version have shown that it works pretty well and the biggest factors in pupils’ learning success is the support by the supervisor and the concepts the pupils already know.

Fig. 9: FREI-Exoplanet-Website during the experiment.

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C. *Notes on the use of the third version in the school laboratory and in regular lessons at school*

In a first step, the FREI experiment will be further tested and improved in the school laboratory. It will initially replace the second version of the transit experiment and form its own station in the experiment cycle at the school laboratory. Following the testing and further development, the experiment will also be made available to teachers via the Internet for their regular lessons. The experiment can be used as a demonstration experiment as well as a student experiment. It should be noted that only one user at a time can perform the experiment. The method "student experiment" can be realized as part of a learning cycle or as homework. Worksheets are developed for all these options.

V. OUTLOOK

The current version of the FREI experiment consists of three different setups which deal with different aspects of the transit method and the light curve. In a next step, the experimental setup will be further supplemented so that additional aspects can be taken into account. For example, with the help of the FREI experiment, the search for exomoons should be considered more closely. In addition, the experimental setup can be extended so that the phase effect of exoplanets can be considered.

ACKNOWLEDGMENT

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Microsatellite Flyby to the Moon’s South Pole

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Abstract—**Small satellites have become one of the most relevant technologies nowadays, however their purpose is mostly academic. This paper summarizes a project of a CubeSat that begins its journey on a Geostationary Transfer Orbit (GTO) and ends up performing flybys to the Moon’s south pole, aiming to gather observations of lunar craters, in order to find iced water crystals. This mission gives an innovative and low-cost solution for an interplanetary mission, demonstrating the capability of CubeSats.**

Keywords—CubeSat; Moon; NANOSTAR; Student Design Challenge

I. Introduction

In the late 1990s, a spacecraft called Lunar Prospector sensed large amounts of hydrogen at the Moon’s poles. After two years, NASA developed the Lunar Crater Observation and Sensing Satellite (LCROSS) mission that reached out and touched the hydrogen detected on the Moon. The lunar soil was analysed, and it was proven that there are, in fact, ice crystals of water on the Moon’s poles [1].

With the growing interest of sending humans to the surface of Mars, finding big quantities of water on the Moon would allow the creation of an important lunar outpost [2].

Past and future missions such as LunaH-Map, Lunar IceCube, Lunar Flashlight and LunIR provided important data during the project presented in this paper.

This paper is organized as follows: section II describes all the subsystems of the satellite. In section III, the risk analysis and mitigation are introduced. Finally, the conclusions about this project are presented in section IV.

II. Mission Analysis and Satellite Design

A. Mission Analysis

The mission designed has 7 different phases. Firstly, the satellite is placed in the desired orbital location from its initial position. Then, one loop sequence is established with the objective of raising the orbit apogee and approach the satellite to the lunar orbit. After the loop sequence, the satellite must be placed in the desired orbital location to start the lunar transfer that will place the satellite in the Moon’s south pole, performing the first flyby. Then, it will perform one orbit change and it will propagate to the new orbit apogee where it will start the manoeuvre to perform a second and closer flyby. After this last orbit change, the satellite will orbit the Moon and begin transferring data to Earth.

The total Delta-V required with margin, is around 1319m/s.

The trajectory of the mission was carefully analyzed using the General Mission Analysis Tool (GMAT).

B. Payload

A camera is used to take pictures of the lunar surface; however, it is not enough to check whether the hydrogen found on a specific crater on the Moon is in the form of water (H_2O) or hydroxyl (OH). So, one needs to add spectrometers to the payload that examine light emitted or absorbed by materials to help identify their composition. The Neutron Spectrometer System (NSS) and the Near-Infrared Volatile Spectrometer System (NIRVSS) are the spectrometers used.

C. Space Propulsion Subsystem

The selected propulsion system is the BGT-X5, a green monopropellant chemical thruster designed by Busek. This thruster operates with AF-M315E, a very stable propellant that provides 10% higher Isp, and 45% greater density than the highly toxic hydrazine, therefore allowing a smaller and lighter propellant tank. The system has 1U volume and can be scaled by adjusting the size of the propellant tanks. With nearly 225s of specific impulse and 500mN of thrust, the estimated time to reach the Moon is of approximately 42-43 days. Given the calculated Delta-V, and applying the Tsiolkovsky equation, the estimated propellant budget is 6.6kg.

D. Attitude, Determination and Control Subsystem (ADCS)

This subsystem is composed of a Cube ADCS 3-axis Integrated Unit (IU) from CubeSatShop that combines different attitude and navigation components into a single part with the aim to provide a simple solution to the satellite’s requirements [3]. Some components of this IU include reaction wheels with pointing accuracy of 8.727e-3rad (0.5°), gyroscopes and accelerometers.

The IU has a Cube Computer module, which is used as main on-board computer and main storage (2GB) for the data generated by the camera.

E. Communications Subsystem and Ground Segment

The CubeSat X-band patch antenna from EnduroSat is used in this subsystem. It has operating frequency between

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8025MHz and 8400MHz and radio frequency output power up to 4W. From the same manufacturer it was chosen the X-band transmitter with the same frequency range.

The NSS (New Space Systems) GPS Receiver from CubeSatShop allows a more reliable transmission signal, with knowledge of time and other features.

The final link budget for the satellite is 33.7dB, which will be established by a ground station from ESA located 77km west of Madrid, Spain.

The satellite's antenna transmission speed is 10000bps, so to transmit the estimated 10MB of data of each flyby one will need about 8400s. According to GMAT, each contact periods, while orbiting the Moon, will be around 40000s, so each transmission will be done easily after each flyby.

F. *Electric Power Subsystem (EPS)*

For the satellite designed in this paper the average power is 36W and the peak power is 51W, these values are in excess. One must size a triple junction Gallium-Arsenide (GaAs) photovoltaic system using the above power budget values, GMAT, constants from the literature and equations from [4].

The solar panel needs to provide 70W during daylight for the entire orbit, which is equivalent to a total area between 0.14m^2 and 0.21m^2. The Custom PMDSAS panel from Pumpkin SpaceSystems is a great choice, because it has coarse sun and external temperature sensors include, and each cell provides 1W, so to get 70W one needs 72 cells for symmetry.

Energy storage is important to provide backup power for long missions. The ideal battery capacity for the satellite presented in this paper is 46.71Wh to 93.42Wh, being the Intelligent Protected Lithium Battery from Pumpkin SpaceSystems a good option.

To control and regulate the power in all subsystems it is used the NanoPower P60 from GOMspace.

G. *Mechanical Design and Structure*

After several iterations, a 6U configuration was obtained which allows to accommodate all the satellite's components with 14kg of total mass. The structure from EnduroSat is a good choice.

More than half of the satellite's volume is for the chemical propulsion system, because it requires a large amount of propellant to reach the Moon.

When the satellite is executing a flyby, a sliding door will open, exposing the camera and the spectrometers. The ADCS is located on the centre of gravity, so that the reaction wheels perform less effort during manoeuvres.

Inside the satellite, there are gimbals that fold the solar arrays in order to retract them to the satellite's external structure. The solar arrays can reach high temperatures, so they must be placed away from the payload and other subsystems.

The antenna is placed in the opposite side of the payload, so it can be more easily pointed towards Earth after each flyby.

H. *Thermal Control Subsystem*

The Multi-Layer Insulation (MLI) is a well-known type of passive thermal method that is used to reduce the heat exchanges by radiation between the external surfaces of the satellite and the environment. The MLI consists of several layers, where the surfaces turned to the space and the satellite are made of Kapton and the layers between the two surfaces are made of Mylar, which is highly resistant and dimensionally stable by high temperature action.

III. Risk Analysis and Mitigation

The damage of electronic components due to Van Allen radiation belts has a very high probability, however with the use of component redundancy it only represents a very low impact.

If the altitude of the first flyby exceeds the required margins for the second one, it will be necessary a more profound trajectory analysis, this represents a medium probability and impact.

If the satellite is unable to transmit data to Earth, it will attempt to communicate with another ESA ground station. The ADCS failure can be overcome with redundancy, e.g. more reaction wheels. These two risks have a very low probability with high impact.

The thruster failure has a very high impact on the mission and cannot be mitigated, however the probability is very low.

Battery cell failure has low probability and impact because of the high redundancy (8 cells).

IV. Conclusions

The preliminary design gives an important path that must be followed regarding the satellite project, where an iterative process must be done in order to get the final optimal solution.

The satellite mission that was given in this paper resulted in the winning solution for the NANOSTAR Project.

Acknowledgment

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UK Analogue Mission Research: The Case for STEAM Education and Outreach

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With little access to practical opportunities within the space industry for UK students, we have founded the UK Analogue Mission (UKAM) to provide motivated students with the platform to develop their skills and knowledge for their future careers. We believe that by utilizing our network and expertise, we can use UK-led space analogue missions to connect students from various disciplines and elevate the potential of the next generation of students.

There is a rise in popularity and demand for analogue missions across the globe. Organizations in Austria and Israel [1][2] are using these initiatives to raise human spaceflight awareness to the public, as well as providing opportunities for students involving habitat design, experiments, and mission planning.

Our goal is to increase the UK's human spaceflight capabilities and collaborate on the global stage with our own British astronauts. The strength of this was demonstrated by Tim Peake and his Principia mission which invited hundreds of students to the Science Museum in London and spurred a new wave of interest into UK spaceflight activities. The UK Space Agency (UKSA) Space Environments and Human Spaceflight Strategy [3] was further evidence of this, where David Parker argued that the UK should be "exploiting the unique opportunities for growth which human spaceflight and associated research programs can offer". Analogue missions provide a valuable niche and enrich the desire to go to space.

Setting aside the importance this platform has for students, analogue missions simultaneously benefits technology demonstrations to raise Technology Readiness Level (TLR) in preparation for future space exploration. Exposing students to these demonstrations is a great way to stimulate inspiration to develop current and future innovations for the advancement of the space industry.

With this ever-evolving industry and the rapid acceleration of innovation and technology, analogue missions provide a rich platform for students, young professionals, and organizations to come together for unique collaboration opportunities. Utilizing resources and expertise across all disciplines, we will elevate the UK space industry onto the international playing field.

Keywords— analogues, demonstrations, STEAM, students

I. Introduction

Science, Technology, Engineering, Arts and Mathematics (otherwise known as STEAM) have seen a large rise in popularity over the last few years. With this, there has been an increase in the number of organizations dedicated to providing STEAM learning resources, outreach events, education programs and more to ensure the enthusiasm for these subjects does not waiver. That being said, there are still limited opportunities for students and young professionals to get involved in practical activities that contribute to research and development (R&D) to drive innovation and technology.

One of the topics known to engage the general public is human spaceflight. Moving forward, this can be a strong tool used to help inspire the next generation of enthusiasts to follow an education, and consequently a career in STEAM subjects. Astronauts are generally thought to be the 'glamorous' part of space exploration and this is what the younger generations typically think of when they consider activities in space. Educators can use this passion as a starting point to teach the public about the other uses of space and the possibilities available to get involved in STEAM in general.

A way in which we can harness this passion for space education is analogue missions. An analogue mission is a situation, environment or event on Earth that replicates the conditions of outer space, or another celestial body. These can be used to test the performance of new technologies destined for other planets or put the human body through similar effects as living and working in off-world environments, helping us learn, practice and prepare for the future. Analogues also allow us to understand the organizational challenges involved when living in outer space. Astronauts in space and living on other worlds may seem like something that is not readily accessible to the general public, but by using analogue missions, we can demonstrate the technologies involved in human space exploration, here on Earth.

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The problem we address in this paper combines the need for more STEAM education activities, lack of practical opportunities for young people in innovative STEAM projects and the absence of a UK human spaceflight program. We present our solution to this as the UK Analogue Mission, a not-for-profit company founded in 2018 to address the gaps in the UK space industry and provide a platform for technological advancements in space technology.

II. STEAM

The number of people studying STEAM subjects in Higher Education in the UK has generally increased over the last few years. From the academic year 2013/2014 to 2017/2018, the number of students studying STEAM subjects per year has increased by nearly 73,000 as shown in figure 1. This has been due to a rise in government initiatives and new organizations looking to promote career paths in technical disciplines.

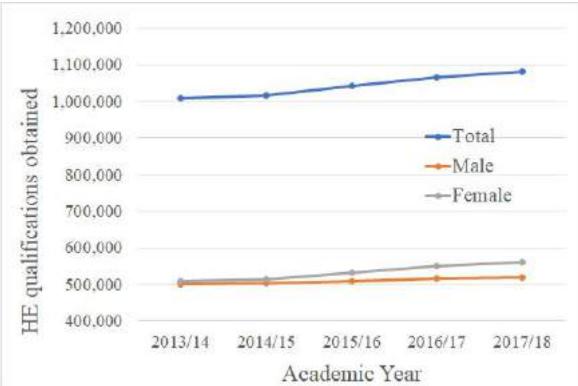

Figure 1 - Number of students in Higher Education Programs [4]

Despite this rise, it was reported in the Engineering UK 2018 report [5] that 61% of businesses in the UK are not confident that there will be enough highly skilled candidates to fill their job vacancies in the future. To aid in solving the problem of the increasing demand for these candidates, opportunities should be made more readily available to students, to participate in practical projects and to further their skills to complement academic knowledge. In the space sector, opportunities of this kind are particularly rare and occasionally not well advertised, as outlined in a paper presented at the SSEA 2018 [6]. This is something that must improve promptly for alignment with the government strategy laid out in 2017 [7]. One of the main focus points was the crucial role of education in narrowing skills gaps through driving skills, economic growth, and productivity. This was heavily welcomed by the engineering community.

Practical STEAM projects as an aid to the educational curriculum provide students with the opportunity to enhance their 'soft skills'. These projects can help teach creative problem solving, critical thinking, project management, team collaboration, and systems-level thinking. The kind of skills mentioned here are often difficult to demonstrate in a classroom environment, but competitions such as the Spaceport America Cup [8], European Rover Challenge [9] and University Rover Challenge [10] provide excellent opportunities to put 'soft skills' to use along with educated knowledge. The drawback to these competitions for UK teams is that they are often held abroad and involve high costs to be competitive.

By increasing the number of practical STEAM opportunities available to young people; conducting outreach events to raise the awareness of these programs and communicating the advantages of getting involved, we can inspire the next generation to continue with their studies and begin to close the identified skills gap within the industry.

III. Human Spaceflight in the UK

To date, there have been six British-born people who have been into space, most notably Helen Sharman who flew on the Mir Space Station, Michael Foale, a NASA astronaut who participated in six spaceflights and Tim Peake who famously was the first British ESA astronaut.

Helen Sharman flew to the Mir Space Station in 1991 on the Soyuz TM-12 mission, as part of Project Juno, a joint Soviet Union-British mission funded by a host of British companies. She spent a total of eight days on-board performing mainly agricultural experiments. In the eight years following Helen's mission, she was self-employed as a Science communicator and was awarded the Order of St Michael and St George (CMG) in 2018 for her services to Science and Technology Educational Outreach.

Until recently, the UK government did not contribute funds to ESA's human spaceflight activities. In 2008, the UK Science Minister at the time gave impetus for the UK to change this and to have an astronaut 'icon', to inspire the next generation into studying technical subjects [11], which lead to Tim Peake flying to the International Space Station as part of the Principia mission in 2015. A report published by the UK Space Agency (UKSA) [12] measures the impact that Principia had and states that more than 33 million people engaged with the mission. A part of this included 34 educational projects delivered by UKSA which benefited from over £3,000,000 of funding and engaged nearly 3 million people. The Principia report also revealed that the awareness of the economic benefits of the space industry rose to 43% of the UK public.

The rise of the level of engagement and the amount of interest in space from Tim Peake's mission highlights the value of using human spaceflight as a centrepiece to enhance passion for space in the general public. To build on the enthusiasm generated by Principia, the UK should look to continue and increase the number of space educational activities by using Tim's mission and human spaceflight as a focal point, to teach and engage the public about the UK space program as a whole.

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Tim Peake on his post-flight tour in 2015. Credit: UK Space Agency

The development of a UK human spaceflight program would be in line with the space environments and human spaceflight national strategy, published by the UK Space Agency in 2015 [13]. Highlighted goals of this strategy include utilizing space environments platforms, exploiting the public fascination for human spaceflight for the benefit of encouraging young people to enroll in STEAM subjects, and delivering science and technology for the advantage of terrestrial downstream applications. These aforementioned goals are very much aligned with those set out at UKAM and so the development of a UK human spaceflight program is something that we strongly advocate for. Alongside UKAM, there is already an active foundation in place to establish this with companies such as Blue Abyss [14], who have plans to develop a space extreme environment research, training and test centre, with the UK also having a strong presence in the research field of space medicine.

IV. Analogue Missions

Analogue Missions are activities or projects carried out on Earth that aim to simulate conditions off-world. These can include but are not limited to: the Moon, Mars, and asteroids. These types of missions simulate environmental conditions similar to those on other celestial bodies, to test technology and overcome operational challenges.

Analogues vary in environmental conditions and research focus depending on the organization conducting the mission. For example, the "aquanauts" at NASA's underwater base "NEEMO" learn how to conduct experiments and perform in a "low-gravity" environment [15]. NEEMO analogue vision contrast from that of the Mars Society's Mars Desert Research Station (MDRS), which focuses on biological and geological studies, but also serves as a testbed for technological demonstrations including the "University Rover Challenge" [10, 16, 17]. This challenge looks to improve rover capabilities and tests their potential in performing teleoperated or autonomous tasks that may assist future astronauts in their work. There are also analogues that aim to be multi-disciplinary in their work, such as the Austrian Space Forum (OeWF) "AMADEE" missions, which undertake a wide array of research domains; this took place most recently in 2018, in Oman [18]. The OeWF has over 15 years of analogue experience, providing fields such as astrobiology and mission operations with valuable insights over the past decade. The OeWF have, and continue to undertake a multitude of public events, projects, and internships alongside their analogue missions, which all demonstrate how analogue missions can benefit STEAM education and outreach. For example, student teams from Oman and Austria were selected and trained for the AMADEE-18 mission, where they helped experiment definition and teleoperations, as well as conduct data analysis and presentation at future science workshops. Further, public engagement was achieved through live-streamed participation with several science centers in Austria and Oman. The mission social media campaign achieved a reach of millions on Twitter, as well as several thousand likes on Facebook, suggesting popularity and successful engagement [18].

Austrian Space Forum (OeWF) AMADEE-18 mission. Credit: OeWF/Florian Voggeneder

Analogue missions are becoming increasingly popular; this has been demonstrated by "D-Mars" in Israel, who established themselves in 2017; they have since undergone several analogue missions to the benefit of both professionals and young students [19]. Such projects serve as strong educational facilitators for younger enthusiasts, but also provide researchers from varying disciplines to test their research and technology. With both "Old Space" and "New Space" players proposing missions to the Moon and Mars, such technology and operational challenges are necessary to be explored and understood on a deeper level. Examples of these missions include NASA's "Artemis" Program to the Moon, and SpaceX's goal of "enabling people to live on other planets" [20, 21]. Analogue missions allow technological and operational testing needs to be met and researched in low-cost and relevant fidelity conditions and can be beneficial in:

- Assisting multidisciplinary research (including human factors, engineering, sciences)

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- Influencing new technologies and their application within society,
- Fostering international collaboration,
- Exploring the benefits of human and robotic exploration
- Inspiring the younger generation and the public. [22]

V. Technology Development

Analogue Missions present a unique opportunity for futureproofing, technology demonstration (TD) and research. They have the potential to demonstrate off-world human-machine interfaces with realistic, simulated circumstances. Stressful situations, confinement, interpersonal experience, and unfamiliar environments all have the ability to affect human performance and hence user-operated technologies.

TD is an important component of human spaceflight missions, with the Space Technology Mission Directorate and the Advanced Exploration Systems [23] [24] programs being run onboard the ISS. Technological Research and Development will undoubtedly be present in at least the first human missions to other celestial bodies, helping to pave the way for future technologies such as In-Situ Resource Utilization (ISRU) and Environmental Control and Life Support Systems (ECLSS), making it vital to have experience through Analogue Mission simulation. This also provides opportunities for collaboration or fund generation through companies, organizations or universities wishing to conduct relevant demonstrations or research, whilst potentially offering them publicity and exposure. In this context, TD is usually conducted through pre-determined experiments to test the capabilities of technologies and the effect of the human condition in their performance.

The type of technology that can be demonstrated during an analogue mission is dependent on the type of mission. This includes the mission concept and intended outcomes, the location of the mission and the analogue mission crew. The location is a crucial factor because it defines the compatibility of the environment with the technology i.e. whether the mission is designed for a Lunar or Mars simulation. The mission crew is another important factor to consider for the analysis of team structure, individual training, and experience. For example, a mission in which the participants are confined within their habitat dictates the usefulness of the testing that can be completed; there would also be vast differences in the technology applicable to a mission on a glacier, and a mission in the desert.

Some examples of the types of technology demonstrated from current analogue missions, such as AMADEE, MDRS, DMARS, and NEEMO [10, 15, 16, 17, 19, 25], include:

- Navigation Systems
- Geographical survey drones
- Biomedical sensors
- EVA suits
- ISRU or surveying rovers
- 3D printers
- Geological survey hardware
- Hydrological survey hardware
- Astrobiological/Biotechnology research payloads
- Volatile Organic Compound (VOC) sensing systems
- Habitats
- Mobility Vehicles
- Communication Systems
- Agricultural Technologies

These examples demonstrate the rationale for analogue missions as a testbed for any technology with off-world applications that can give benefit to or benefit from a human component.

Whilst the UK has developed and contributed to technologies within unmanned space exploration missions in recent years, such as ExoMars, Bepicolombo, and InSight, there is a lack of demonstration platforms involving a human component. There is an exception in the Airbus Stevenage Mars Yard - a testing ground for the ExoMars rover, but this remains reasonably exclusive and designed for the testing of autonomous systems. A UK-run analogue mission could provide a more accessible, diverse platform for TD, applicable to technologies designed with a human interface.

There is great potential for TD to provide STEAM outreach opportunities, by allowing students of various ages to provide technologies, ideas or experiments to a mission, as showcased by the OeWF with their Junior Explorers' Experiments [18]. These opportunities allow students to develop their 'soft skills' such as critical thinking, team-work, and problem-solving, and provide students in education with relevant, hands-on skills that can be carried forward into higher education or advance their careers.

VI. UK Analogue Mission

At UKAM, we aim to be this platform for engaging students in STEAM education. Our goal is to first invite students from the various disciplines to work with our architects when building our habitat. The purpose of this is to highlight the requirement for specialists in different fields when building space habitats. UKAM has readily identified a lack of awareness within STEAM disciplines for the applicability of their knowledge within the space industry. In addition, UKAM has designed several mission competitions targeted at UK universities tailored to captivate students across all disciplines. With this in mind, UKAM is working hard to collaborate closely with a variety of universities not only through partnerships but also through utilizing the habitat for the purposes of attaining specific course credits when participating in missions and projects. The involvement of universities is essential in increasing student engagement as this is the frontline for student access, it is in this light that UKAM is offering tailor-made in-house lectures for STEAM subjects by utilizing our specialist network within the space industry. It is through our large array of networks that we hope

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to connect our students with the next stages of their future space careers.

VII. Conclusion

The challenges that lie ahead in regard to STEAM education and involvement have been presented and we have highlighted the major role that human spaceflight and technology development can play in overcoming these challenges. As a solution to this, we have introduced the UK Analogue Mission (UKAM) which has the aim of simulating crewed spaceflight missions, providing practical opportunities in exciting and innovative projects, reigniting the passion for human spaceflight within the British public and promoting international and interdisciplinary STEAM collaboration.

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The CADMUS experiment in the frame of the BEXUS Programme: an educational perspective

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***Abstract*—CADMUS was a student-made experiment with the aim of measuring the flux of muons at different altitudes and experimentally verifying time dilation, one of the effects predicted by the Special Relativity Theory. It was developed in the frame of the REXUS/BEXUS Programme and flew to the stratosphere on a high-altitude balloon in October 2017. This paper discusses its development, from inception to launch, from the perspective of space educational activities.**

Keywords—student-made experiment; particle detector; cloud chamber; muons; Special Relativity Theory; time dilation; REXUS/BEXUS Programme; stratosphere; high-altitude balloon; education

I. Introduction

The Cloud chamber for high Altitude Detection of Muons Under Special relativity effects (CADMUS) was a student-made experiment consisting of a cloud chamber and a video recording system, with the aim of measuring the flux of muons from the ground up to the stratosphere, and through the computation of muons' half-life, verifying one of the effects described by Albert Einstein's Special Relativity Theory: time dilation.

The idea was born during the fall of 2016 out of a small group of Engineering Physics' bachelor students, and it was then presented to the REXUS/BEXUS Programme, which allows university students to fly their experiment ideas to the border of space, either with a sounding rocket or with a stratospheric balloon. This programme entails an exigent process of selection and supervision ensuring that students succeed throughout the development of the experiment.

The team behind CADMUS was composed of five second-year university students, two of them studying Engineering Physics, two of them studying Engineering Physics and Mathematics, and the fifth one studying Aerospace Engineering and Telecommunications Engineering. Thus, the idea was to have a team with a strong background on physics to define the proper performance requirements for such an experiment to produce valuable data, and to later conduct the scientific analysis of the results, but also with the engineering background required for the design and development of the experiment, specially with regard to the particularities of near-space missions.

The selection committee of the REXUS/BEXUS Programme chose the experiment to fly on the stratospheric balloon of mission BEXUS 24 in December 2016. The project entered then into a one-year phase of design and development, passing a Preliminary Design Review (PDR) in March 2017, a Critical Design Review (CDR) in May 2017, an Integration Progress Review (IPR) in August 2017, and an Experiment Acceptance Review (EAR) in September 2017. CADMUS was finally launched on the 18th of October of 2017 from the Esrange Space Center near Kiruna, Sweden.

Although the experiment could be controlled and its systems performed nominally during the flight, due to unforeseen causes that are explained in Section 4, no quality images of traces of muons could be captured, and thus, the scientific goal of measuring the flux of muons was not reached.

Through the sections of this article, the idea behind the experiment, its design and development, as well as a description of the launch campaign and its results, are presented. Each section tries to compare the described processes to the educational background of the team members in terms of university courses' syllabus. Also, a particular section focusing on outreach and educational activities performed during the project is included.

About REXUS/BEXUS:

The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Agency (SNSA). Through the collaboration with the European Space Agency (ESA), the Swedish share has been made available to students from all ESA Member or Cooperating States. EuroLaunch, the cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from DLR, SSC, ZARM, and ESA provide technical and logistic support to the student teams throughout the project.

II. The Experiment

Muons are elementary particles, from the family of leptons, which primarily originate at 15 km of altitude due to the interaction of cosmic rays with the atmosphere. They are unstable -with a half-life of 2.2 μs- and negatively charged particles.

Given their short half-life of 2.2 μs, by applying Newton's laws of motion it can be shown that it is impossible to detect muons at sea level, since they should have disintegrated long before reaching the ground. In other words, Newton's laws of

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motion tell that a particle moving at about the speed of light, such as a muon, will take more than 2.2 µs to travel 15 km. However, muons are actually detected at sea level.

This challenging fact is explained by the Special Relativity (SR) Theory. One of the effects described by this theory is time dilation, which can be described as time seeming to pass slower for observers at a different system of reference with respect to objects moving at velocities close to the speed of light. This would explain why muons are able to reach the ground: as they are travelling close to the speed of light, their half-life seems to pass more slowly than 2.2 µs for us, and thus, they are able to travel longer distances. By measuring the flux of muons at different altitudes, their half-life can be calculated.

This SR effect and, more generally, the overall SR Theory are normally not included in the syllabus of secondary education courses in Physics. Basically, the courses focus in the introduction of Newtonian physics to students. At university level, Relativity theories are covered in the degrees of Physics and Engineering Physics. Relativity is normally taught as an elective course in the third or fourth year of the degree. Although teaching the principles of such theory to pre-university students is clearly beyond the scope and possibilities of those courses, exposing students to the limitations of Newton's theories can be beneficial, specially in terms of understanding how scientific theories evolve and how they represent the best approximations that we have so far for explaining certain complex phenomena. Experimenting with the time dilation effect that muons undergo can be thus, a good introduction to those limitations of Newtonian physics.

With a similar goal, and to a greater extent, CADMUS experiment wanted to empirically reconfirm the time dilation effect in muons, by measuring the flux of muons mentioned before. In order to do so, a cloud chamber was built. A cloud chamber is a type of particle detector which consists of a pressurised chamber, filled with alcohol, cooled at the bottom and heated at its top. The gradient of temperature across it generates an atmosphere of supersaturated alcohol vapour. Due to this atmosphere, charged particles such as muons leave traces as they traverse the chamber. Depending on the type of particle, the trace will be more or less straight and thick. There are many designs of cloud chambers, some being quite rudimentary and some others being more complex. Also, apart from cloud chambers, simple electronic muon detectors can be built. Some articles such as [1] and [2] propose simple ways in which particle detectors can be easily built, suitable for the context of a secondary school laboratory and also a university one. The design of the cloud chamber of CADMUS is explained in Section 3.

III. Engineering Design

In this section, the design of the experiment is described *grosso modo*. It is divided into diverse subsections (mechanical, electronics, thermal, software) in which the focus is set into different experiment's subsystems.

A. Mechanical design

The experiment is composed of three different structures: the primary structure, the secondary structure, and the tertiary structure, each of them serving specific purposes.

The primary structure is the skeleton of the experiment. It withstands all the payloads of the experiment, and it allows the connection of the experiment to the gondola of BEXUS 24, where other mission experiments are placed. The secondary structure protects the experiment from the outside, both from impacts and extreme temperatures. It is compounded of 6 aluminium panels that cover all the primary structure. Over the aluminium panels, thicker Basotect® panels are placed to thermally protect the experiment. These panels are also covered by a thin layer of thermal blanket. The tertiary structure is internal and consists of mountings that support the electronic subsystems and the recording camera.

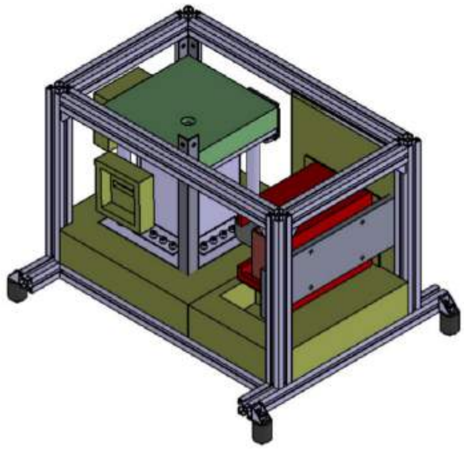

Fig 1: Design of the experiments primary structure (in grey) and tertiary structure (in red, yellow, and green). The cloud chamber is also visible in lighter gray.

Finally, inside the experiment, the cloud chamber also occupies an important place. Below the cloud chamber, there is a structure specifically designed to contain the cooling dry ice.

The aluminium bars of the primary structure and the aluminium panels of the secondary structure were designed using CAD tools -in particular, SolidWorks-, and were sent to a factory for its production. In fact, the use of CAD tools such as SolidWorks is taught in universities in first-year courses covering technical drawing, in degrees such as Aerospace engineering, Industrial engineering, and Mechanical engineering, among others. Thus, the team had the necessary background to produce such designs, and the project was a good opportunity to put into practice what had been learnt at class before. Other than that, the pressurised chamber was designed and built by ZARM.

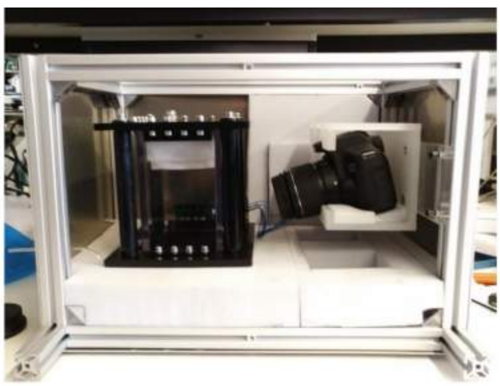

Fig 2: Picture of the experiment's structure with the cloud chamber and the recording camera inside.

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B. Electronics design

The principal goals of the electronic subsystem are to power the heaters on top of the cloud chamber so that the supersaturated alcohol atmosphere can be created, power the video recording camera which has to capture muon traces, and illuminate the chamber for the videos to have the required quality. This subsystem also powers the experiment's computer, a Raspberry Pi which is able to control the heaters, camera, and lighting blocks, measure essential parameters of the experiment -such as temperatures- through sensors, save data, and transmit data to ground.

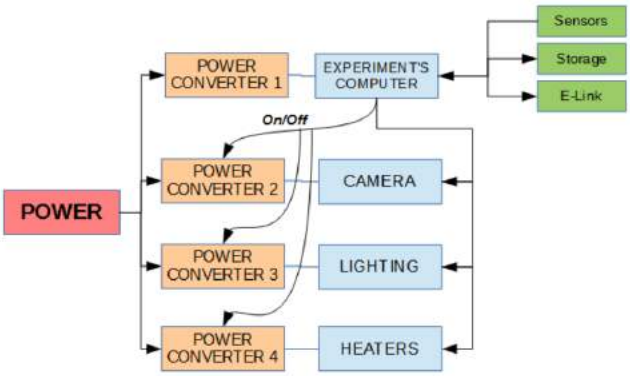

Fig 3: Block diagram of the components of the electronics subsystem and their interrelations.

In order to decrease the probability of losing the mission due to a failure in an electronic element, redundancy was implemented for some components, which were doubled. For instance, the Raspberry Pi, the heaters, the lighting block, and the sensors were doubled, and the auxiliary doubles could be turned on if the primary elements failed.

For each electronic subsystem, PCB were created using the free software tool KiCAD, and were sent to be printed at a factory. Sensors and electronic components such as DC-DC converters were also bought. Afterwards, in an electronics laboratory, everything was assembled and soldered on the printed PCB. A member of the team attended a soldering course given in the frame of the BEXUS programme, which helped gaining the necessary skills to properly solder components to the boards. Unlike soldering experience, team members already had basic knowledge on circuits theory and tools for the design and simulation of circuits from university courses. Degrees such as Telecommunications engineering, Electronics engineering, etc. but also Engineering physics include courses on circuit theory and electronics.

C. Thermal design

Maintaining the temperature inside the experiment in a specific range is important due to two reasons: to ensure that it is always in the working range of electronic components, so that they don't fail; and to ensure that the critical temperature gradient is maintained inside the cloud chamber. To attain this goal, the experiment counts with one passive thermal control system and one active thermal control system.

The passive thermal control goal is to maintain the internal temperature of the experiment within slow variations, and always above -40 ºC, so that electronic components work properly. It has to protect from extreme outside temperatures, but also from extreme internal temperatures (those coming from the dry ice container and also the heaters above the cloud chamber). The passive thermal control is made up of Basotect® panels covering the experiment's exterior panels, and covered by Mylar blanket.

The active thermal control goal is to maintain the necessary temperature gradient inside the cloud chamber to generate the supersaturated alcohol vapour. It is an active thermal system, as it automatically checks for the temperature on top of the chamber and at its bottom, calculates the gradient of temperature between both points, and turns off or on the heaters accordingly, in a hysteresis loop, to obtain the desired gradient.

To check that the thermal design was good enough, heat transfer studies had to be performed. These studies were basic and based on thermodynamic calculations regarding materials' thermal conductivity and components' heat generation. The team relied on knowledge from Thermodynamics university courses, which are offered in a wide variety of engineering degrees, for instance those related to the team members (Engineering Physics and Aerospace Engineering) but also in others (such as Industrial Engineering).

D. Software design

Two important pieces of software were built for the experiment: the experiment's on-board computer software, and the ground segment control software.

The on-board software was programmed in Python and run in a Raspberry Pi. A watchdog ensured that the Python script run continuously. The main goals of the software were to continuously collect data from sensors, send it to the ground via an Ethernet link provided by BEXUS, and continuously read commands coming from the ground and act upon them by performing the necessary actions -turning on/off lighting, heaters, etc.-.

The ground software was coded in C# and it run in a Windows 7 laptop. Its main purpose was to display information coming from the experiment, and allow the ground segment operator to send commands to the on-board computer.

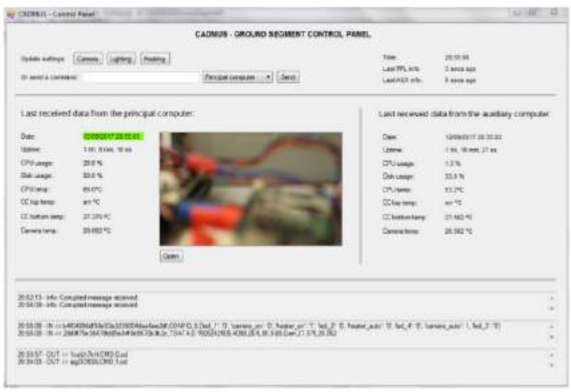

Fig 4: Picture of a test of the ground segment software, showing information incoming from the experiment.

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The team relied on knowledge coming from university programming courses, but also on experience gained by members while attending *hackathons* and other coding events, and while having worked on previous personal projects. All engineering degrees offer courses on programming, but a Telecommunications Engineering course providing knowledge about C# and socket communication was of special interest for the ground segment software design. Engineering Physics studies also include a course on Python, which was useful for the on-board computer programming.

IV. Launch Campaign & Results

The launch campaign of CADMUS and all of the other experiments flying on mission BEXUS 24 took place from October 13th to October 22nd of 2017. During these days, the experiment arrived at the Esrange Space Center near Kiruna, was assembled and prepared, and was tested to ensure that it worked properly and that it did not interfere with any other experiment flying on the same mission. After successful tests, the experiments of BEXUS 24 were launched on the 18th of October. Hours after the launch, they were recovered and brought back to Esrange. A fast, first analysis of the recorded videos was performed by the CADMUS team. A brief presentation on the experiment's preliminary results was also given on the last days of the launch campaign.

During the course of the whole mission, the experiment transmitted the intended technical and scientific data regularly, and could be controlled through the use of predefined commands. Thus, it performed as expected from the engineering point of view.

However, the heaters present at the top of the cloud chamber -needed to create the temperature gradient for the isopropyl alcohol to supersaturate- had to be activated through a remote command moments before the launch, to ensure that the dry ice present at the bottom of the chamber would not melt before the launch, since a long time can pass from experiment start-up to the actual launch.

The heaters could not be turned on manually moments before the launch, as it was planned, due to the instability of the communications link to the experiment. The communications link used wireless technology and its power had to be reduced during the phase previous to the launch, to protect workers on the launch area from EM radiation, thus degrading its performance. Once the BEXUS 24 launched, the power of the communications link was increased to its nominal value, and the link started working properly again. The command to turn on the heaters could then be sent, but precious time had been lost, and the necessary gradient of temperature inside the cloud chamber took longer to create.

The necessary temperature gradient was finally obtained during the float phase of the mission, above 15 km of altitude. Thus, no traces could be formed in the cloud chamber during the ascent, the most interesting part of the flight. The descent was fast, and the recording camera was focused for ascent conditions -due to the consumption of dry ice at its bottom, the cloud chamber descends and the focus of the camera changes during the flight-, and no relevant data could be collected also during the descent.

V. Outreach

An important part of any BEXUS project is to communicate the experiment's existence, goals, development, and results, to the general public. It is not only important to learn by doing the project, but also to teach others. One of the first outreach activities was to explain the project to fellow students, professors, and administrative staff of Universitat Politècnica de Catalunya, our university. Thus, news were published on the websites of Engineering Physics degree, and the EETAC and CFIS schools.

Also, accounts on social media websites such as Facebook. Twitter, and Instagram were set up and information was posted regularly about the progress of the experiment development. The team also got in touch with the Communication Service of the university, which contacted press and media to share our story with them.

Following that, CADMUS appeared on newspapers, making it to the front page of *La Vanguardia*, the third most read newspaper in Spain (with about 600 000 readers), on May 2nd 2017 [3]. It was featured on radio programmes such as *Herrera in COPE,* the second most listened morning radio show in Spain (with about 2 million listeners), *El món a RAC1,* the most listened in Catalonia region (with about 800 000 listeners), and *Informatius de Catalunya Ràdio* [4]. It also appeared on TV programmes such as the nightly news *Telediario* in national television *La 1* (with about 2 million viewers) on May 2nd 2017 [5], and local *Esplugues TV* [6]. Thus, the project reached millions of people in Spain, who discovered more about muons, special relativity, and time dilation.


LA VANGUARDIA .cat
Nova York exhibeix la connexió entre Miró i Calder
Caçadors de partícules: de la UPC a l'Agència Espacial
Macron es gira ara contra Brussel·les per guanyar suports
La Generalitat estendrà la taxa del sucre a la brioixeria industrial

Fig 5: Picture of the front-page of La Vanguardia featuring CADMUS.

The project was not only mentioned by mass communication media, it appeared as well in specialised media such as *Actualidad Aeroespacial* (focused in aerospace news) [7], *Fulls dels Enginyers* (engineering news) [8], and *Noticias de la Ciencia* (science news) [9].

One of the outreach activities of the project consisted in visiting *Rubén Darío*'s public primary school in Barcelona, Spain. A short talk was given to 30 primary students of 4th grade (9 to 10 years-old). The talk was focused on explaining

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the scientific method to kids and to encouraging them to keep studying and to follow careers in science.

Previously, the teacher had worked with the students with adapted material regarding the project. The kids worked on the project topics from an interdisciplinary point of view, they read the newspaper article published by *La Vanguardia*, and draw and painted muons and cloud chambers, among other activities.

Fig 6: Picture of the teacher and kids from Rubén Darío's school and one of CADMUS members, after the talk.

VI. CONCLUSION

The inception, the design, the development, the launch, and the results analysis conducted for CADMUS have revealed to be a truly remarkable educational activity, in which knowledge coming from different disciplines of science and engineering and learnt at diverse bachelor degrees was put into practice. Self-teaching also played a very important role, as many things had never been done before by team members.

The project gave as well its members a great opportunity to master skills at project management and outreach, and many other abilities not directly linked with science and technology (such as giving presentations, documenting the project, requesting funding, managing a budget, talking to material providers, etc.). Finally, the project also had a big external impact in terms of educating the general public, teaching millions of people in Spain about muons and special relativity, and inspiring little kids and attracting them to science.

Thus, CADMUS can only be described as a truly remarkable and positive educational experience, both internally and externally.

AFTERWORD

For detailed information about the experiment, more linked to its engineering design and less focused on its educational part, please refer to CADMUS' Student Experiment Documentation available at [10].

ACKNOWLEDGMENT

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Stratospheric Balloon Flight of Cost-Effective Sampling Bags and High Resolution AirCore to Measure Arctic Greenhouse Gas Concentrations of CO2 and CH4

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***Abstract*— There is little information on the distribution of trace gases in the stratosphere due to the inherent difficulty and high cost of air sampling above aircraft altitudes. This paper presents project TUBULAR, implemented under the REXUS/BEXUS programme. TUBULAR is a student-led stratospheric balloon experiment for low-cost air sampling that reduces the current complexities and limitations of obtaining data on stratospheric trace gas distributions. This technology demonstrator was launched from Esrange, in the Swedish Lapland. The balloon payload included two atmospheric samplers: an AirCore sampler and a bag sampling system. The AirCore sampler was a 200 m long stainless steel tube, which allowed continuous profile sampling during balloon descent. The bag sampling system consisted of six bags, each programmed to be filled at a pre-selected altitude in the stratosphere using a pumping system. This paper presents details on the payload construction and first results obtained by the AirCore sampler.**

Keywords—Balloon Experiments for University Students; Climate Change; Stratospheric Air Sampling; AirCore; Sampling Bags; Greenhouse Gas; Carbon Dioxide (CO2); Methane (CH4); Carbon Monoxide (CO).

I. Background

Trace gases make up less than 1% of the Earth's atmosphere. They include all gases except nitrogen, oxygen, and argon. In terms of climate change, the scientific community is concerned with concentrations of CO_2 and CH_4 which make up less than 0.1% of all trace gases and are referred to as greenhouse gases. They are the main offenders of the greenhouse effect caused by human activity as they trap heat in the atmosphere. Larger emissions of greenhouse gases lead to higher concentrations of those gases in the atmosphere thus contributing to climate change.

Researchers have noted that “the Arctic region has warmed more than twice as fast as the global average - a phenomenon known as Arctic amplification” [1]. An ice-free Arctic Ocean is projected as a realistic scenario in future summers, similar to the Pliocene Epoch when “global temperature was only 2-3°C warmer than today” [2]. Suggestions that additional loss of Arctic sea ice can be avoided by reducing air pollution and CO_2 growth still require confirmation through better climate effect measurements of CO_2 and non-CO_2 forcings [2]. Such measurements bear high costs, particularly in air sampling for greenhouse gas concentrations in the region between the upper troposphere and the lower stratosphere which have a significant effect on the Earth's climate.

II. Proof-of-concept

A. AirCore Limitations

TUBULAR sought to address the limitations of using an AirCore: a stratospheric balloon sampling system using a long and thin stainless steel tube, shaped in the form of a coil, that takes advantage of changes in pressure during descent to passively sample the surrounding atmosphere and preserve a continuous profile. Details of the AirCore mechanism and resulting profiles have been elaborated in detail with past campaigns such as in [3] and [4].

AirCore sampling during a balloon's descent phase results in a profile shape extending the knowledge of greenhouse gas distributions for the measured column between the upper troposphere and the lower stratosphere [3]. Due to the complexities and mass penalties of including a gas analyzer as part of the payload, analyses of the sampled greenhouse gases are done post-flight after recovery of the experiment.

Despite its proven robustness and notable cost-effectiveness, it is difficult to determine the sampling altitudes of an AirCore [5]. Furthermore, an AirCore constrains the choice of coverage area due to the geographical restrictions imposed by the

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irreversible process of gas mixing along the air column sampled in its stainless tube. As such, the sampling region of an AirCore campaign must remain within proximity to research facilities. It is this constraint that motivated the design of TUBULAR to enable sampling in remote locations where fast recovery of the experiment is unlikely, such as in Arctic regions.

B. Alternative to AirCore

The proposed alternative sampling system consists of a series of small independent air sampling bags activated in series during flight. Each sampling bag is allocated a vertical sampling range capped at 500 meters, lessening the concerns associated with mixing of gases and enabling a direct determination of sampling altitude. Furthermore, the use of sampling bags eliminates the production costs of a long coil which is the crux of the AirCore system. Sampling bags introduce their own limitations as the discrete approach to sampling in series does not offer the continuous profile made possible by an AirCore. It is possible to mitigate this decreased vertical resolution by scaling the experiment to include more sampling bags. The choice between using an AirCore or sampling bags thus becomes a trade between sampling resolution, production cost, and remoteness of the target sampling location.

The primary objective of TUBULAR consisted of validating the proposed air sampling bag system. This sampling mechanism is henceforth referred to as the Alternative to AirCore (AAC). Samples collected by the AAC were to be validated by comparing concentrations of greenhouse gases against those found in reference samples collected during the same flight by a high resolution 200 m tube long AirCore, henceforth referred to as the Conventional AirCore (CAC). The secondary objective was to analyze carbon dioxide (CO_2) and methane (CH_4) concentrations measured from samples collected by both systems and to contribute the findings to climate change research in the Arctic region. In order to achieve these objectives, both systems were included in a thermally regulated encasing flown as one of the payloads on board a stratospheric balloon provided by the REXUS/BEXUS programme. The sequences of sampling operations were triggered autonomously based on air pressure measurements translated to altitude. Overriding this autonomous sequence was possible via telecommand. A high level design of the payload is presented in Fig. 1.

III. SAMPLING STRATEGY

A balloon flight goes through three phases: ascent, float, and descent. The AAC contained six sampling bags, two of which were to collect samples during the ascent phase at 18 km and 21 km and the remaining four during the descent phase at 17.5 km, 16 km, 14 km, and 12 km. These altitudes were determined by taking into account the time needed to fill the bags with respect to the ambient air pressure at those altitudes and the projected ascent and descent velocities all while satisfying the target 500 m vertical resolution. The sampling timeline is presented in Fig. 2.

Analysis of the sampled gases was done post-flight, after experiment retrieval, with a Picarro G2401 analyzer located at ground station. A minimum air sample amount of 0.18 L (at sea level pressure) was required for the analyzer to detect concentrations of CO_2 and CH_4. Taking into account pressure changes, the minimum volume of air that was needed to be sampled during the ascent phase were 1.8 L and 2.4 L for 18 km and 21 km respectively. During the descent phase, the minimums were 1.7 L, 1.3 L, 1.0 L, and 0.7 L for 17.5 km, 16 km, 14 km, and 12 km respectively. However, the 3 L size of the sampling bag allowed the experiment to target a sea level pressure air sampling amount of 0.6 L rather than the worst case 0.18 L.

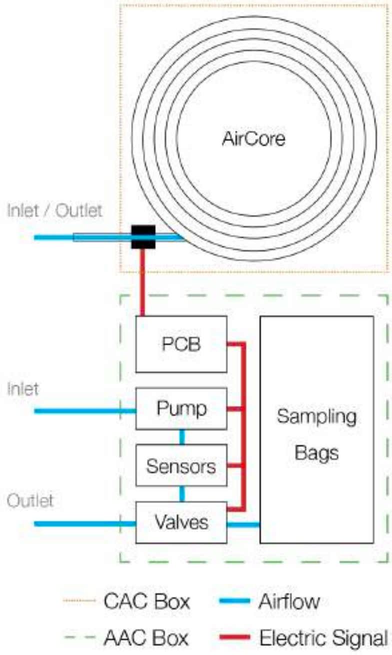

Fig. 1. High level design of the TUBULAR payload.

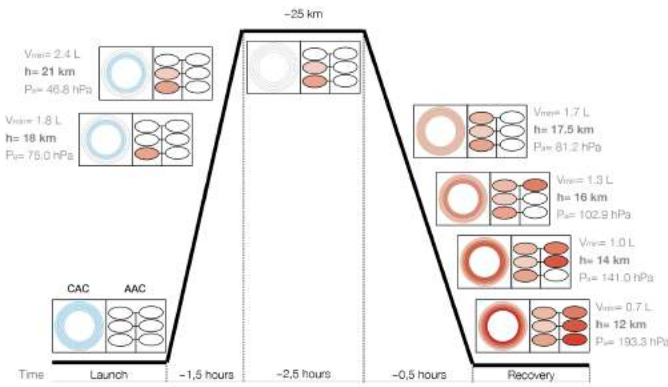

Fig. 2. Air sampling timeline throughout the flight profile for both the CAC and AAC. *Vmin*, *h*, and *Pa* values are associated with the bag sampling strategy. *Vmin* denotes the minimum quantity of required air sample assigned to the allotted sampling range; *h* denotes the target altitudes from which sampling begins; *Pa* denotes the target air pressure values from which sampling begins.

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A. Ascent Phase

From a scientific point of view, the primary region of interest for sampling were at the peak altitudes while the balloon was in the stratosphere. Sampling at these altitudes could not occur during the descent phase due to the gondola tumbling and falling at an average speed of 50 m/s for approximately two minutes after the balloon cut-off [6]. This descent speed was too large for a sampling bag to be filled within the target vertical resolution of 500 m. Peak altitude sampling with the AAC could thus only be accomplished toward the end of the ascent phase, peaking at approximately 27.3 km.

B. Descent Phase

The AAC sampling could only initiate once the gondola descent speed had stabilized at 8 m/s from approximately 19 km in altitude [6]. Passive sampling with the CAC was triggered at the beginning of the descent phase based on air pressure measurements. The CAC descent phase sampling was to be used to validate the AAC sampling mechanism by comparing measurements from both samples and using those of the CAC as a reference.

IV. Setup and Components

The experiment consisted of two boxes side by side, as shown in Fig. 3. This design allowed easy independent access to and manipulation of either sampling system.

The AAC box houses six sampling bags as well as the pneumatic system and electronics. These components were not distributed across both boxes for the sake of simplicity of design, compactness, and mass reduction. Furthermore, a design favoring future re-flights of the AAC systems was chosen over that of the CAC. Both boxes are mechanically and electrically connected as the CAC relies on the onboard computer housed in the AAC for sensor reading, thermal regulation, valve control, and data logging. The AAC pneumatic system consists of a pump, sensors, tubing, and valves.

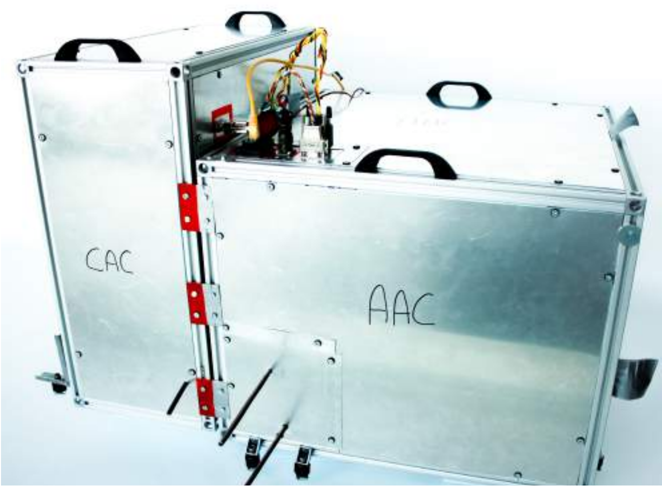

Fig. 3. The flight ready CAC (left) and AAC (right) sampling systems enclosed in their respective boxes. The CAC box containing the AirCore is 0.23 x 0.5 x 0.5 m and 11.95 kg while the AAC box containing the sampling bags is 0.5 x 0.5 x 0.4 m and 12.21 kg. The total mass of the experiment is 24.16 kg.

The mechanical components that were selected to build the AAC sampling system were based on requirements relating to inertness and operational robustness in an extreme atmospheric environment. Extensive ground testing was thus performed to validate component reliability at different air pressure levels up to the projected maximum altitude. For instance, the pump was vacuum chamber tested under an air pressure of approximately 23 hPa while simulating performances at 24 km in altitude. Key components selected for the final design were *Restek* multi-layer foil gas sampling bags (3 L, 10"x10"), *KNF* air pump, *FMI* (Finish Meteorological Institute) magnesium filter tube, *SilcoTek* tubing - SilcoNert® 2000 coated 304SS welded/drawn, *SMC Pneumatics* valves and manifolds, and Swagelok tubing interfaces, connectors, fittings, and unions. Additionally, key electrical components were *Sensor Solutions* pressure sensors and a *Honeywell* airflow sensor.

A. Air Pump

Due to low ambient pressure at stratospheric heights, the AAC needed to be equipped with an air pump to fill its bags with air samples. The air pump had to ensure an intake rate of at least 3 L/min in order to obtain a 500 m vertical resolution at an ascent speed of 5 m/s and a descent speed of 8 m/s.

B. Tubes and Valves

The sampled air traveled from the pumps into the sampling bags via the pneumatic system. Each sampling bag was allocated a sampling altitude range and connected to a dedicated valve via a tube. The maximum operating pressure for the tubes are 150 hPa. The valve's leakage rate is 0.001 L/min. A flushing valve was used to flush the system before each bag would be filled, ensuring that samples came from the desired altitude rather than from leftover air introduced in the tubes from previous sampling.

C. Sampling Bags

The AAC system was designed for ease of use, its internal configuration is shown in Fig. 4. The sampling bags were easily accessible from the sides, allowing minimal handling requirements for manual operations such as pre-launch flushing. Filling the sampling bags during the ascent phase introduced a bursting risk due to the air samples expanding inside the bag during the ascent that followed sampling. Ascent phase sampling thus targeted partial bag filling to a maximum bag pressure of 110 hPa. However, air compression during the descent was a concern with respect to insufficient air sampling in which case the bags had to be fully filled. Descent sampling targeted a maximum bag pressure of 130 hPa in order to ensure that enough samples were collected for analysis. The maximum bag pressure recommended by the manufacturer is 140 hPa.

D. Pressure Sensors

Sampling was triggered by the ambient air pressure readings from sensors located outside the experiment box. When air pressure readings indicated pressures expected at a target sampling altitude, the appropriate sampling valve would be activated autonomously and allow air to flow into the sampling bag assigned to the given altitude. Closing the sampling valve was triggered when one of the following two conditions was met: the maximum pressure difference between the inside and

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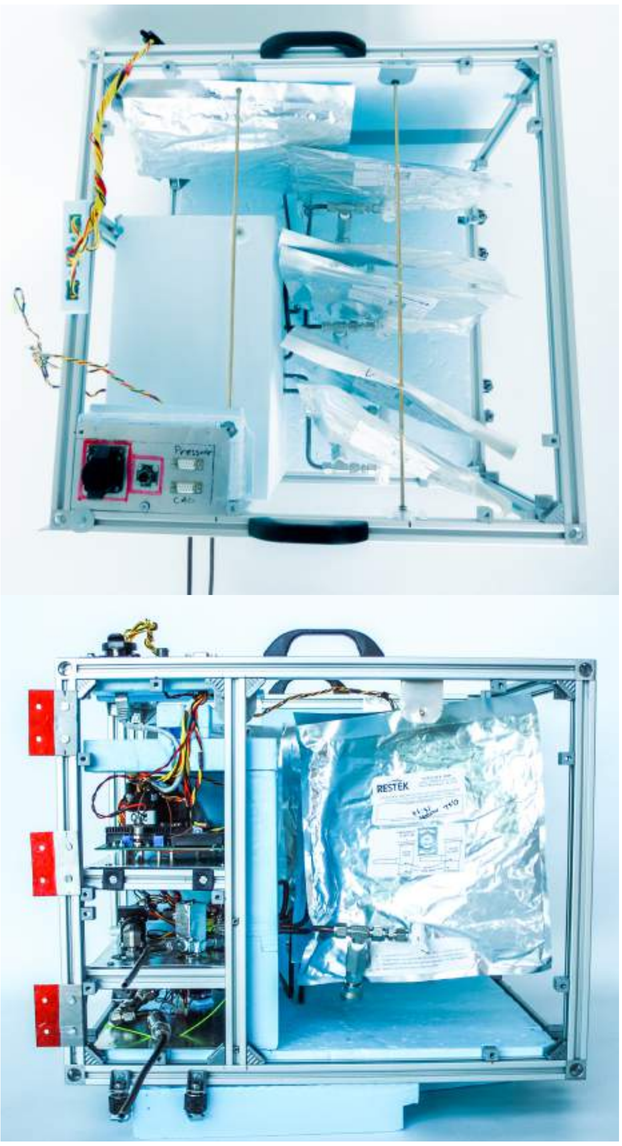

Fig. 4. Restek multi-layer foil gas sampling bags (3 L, 10"x10") in the AAC box, top and front views.

the outside of the bag was reached or a maximum sampling duration had passed. An in-line pressure sensor was used for the former and predetermined sampling durations were calculated for the latter based on vacuum test results and monitored by means of an airflow sensor.

V. Results

A. *Flight Performance*

The flight began nominally with housekeeping data being downlinked as expected. Thermal systems were observed from the ground station to be operating nominally. After takeoff, the onboard software successfully entered ascent mode and thermal management continued nominally for the rest of the flight. The first AAC sampling altitude of 18 km was successfully detected by the software; however, the pump failed to switch on and a full reset of the board followed. After the reset had completed, the software successfully switched back to ascent mode at which point manual mode was set via telecommand in order to attempt to remedy the pump. Unfortunately, all attempts proved unsuccessful during both ascent and descent phases.

B. *Failure Analysis*

Post-flight investigation revealed that all subsystems operated nominally within expected conditions, including the pump. The observed failures were reproduced after introducing a current limitation by setting the bench power supply from 24 V and 1.8 A to 24 V and 1 A. Based on this finding, a lab analysis was conducted which focused on the pump's power consumption. It was confirmed that the experiment was current-limited but the source of this limitation was not discovered.

Concerns on introducing contaminants into the system after it was cleaned imposed access restrictions to the gondola which made it impossible to test start the pump during the pre-fight readiness review. As such, this issue should have been detected with a test plan to start the pump while running on batteries at a lab setting.

C. *AirCore Profiles*

The primary objective of validating the AAC as an alternative sampling mechanism was not achieved. However, the AirCore onboard the CAC system operated nominally resulting in high resolution profiles for CO, CO_2, and CH_4. These profiles are presented in Fig. 5 and the raw data is available as open data from [7].

Trace gas concentrations are measured in parts per million (ppm) and parts per billion (ppb). A decreasing concentration trend is observed for CO_2, CH_4, and CO as the altitude increases. The maximum values are approximately 407 ppm for CO_2, 1.9 ppm for CH_4, and close to 89 ppb for CO.

A sharp decrease of CO_2 can be observed in the first layers above the tropopause. Tropopause altitude was at 274 hPa, about 9.8 km. In the stratosphere, values are lower since the exchange between the upper troposphere and lower stratosphere takes several years [4]. Variability is higher near the ground, which agrees with the idea that CO_2 may have negative and positive anomalies at the surface that are mainly associated with vegetation uptake and anthropogenic emissions [4].

The mixing ratios of CH_4 have a small variability in the troposphere. A strong decrease in the stratosphere is easy to spot with a value of 1.85 ppm near the tropopause and 1.33 ppm at 15.2 km (118 hPa). Variability is higher in the mid-to-upper troposphere and in the stratosphere, which is mostly due to positive anomalies coming from the surface and negative anomalies coming from the stratosphere [4].

It is difficult to draw any conclusions based on measurements extracted from a single sampling flight. Variations of greenhouse gas concentrations would have to be observed through time with data collected over numerous re-flights.

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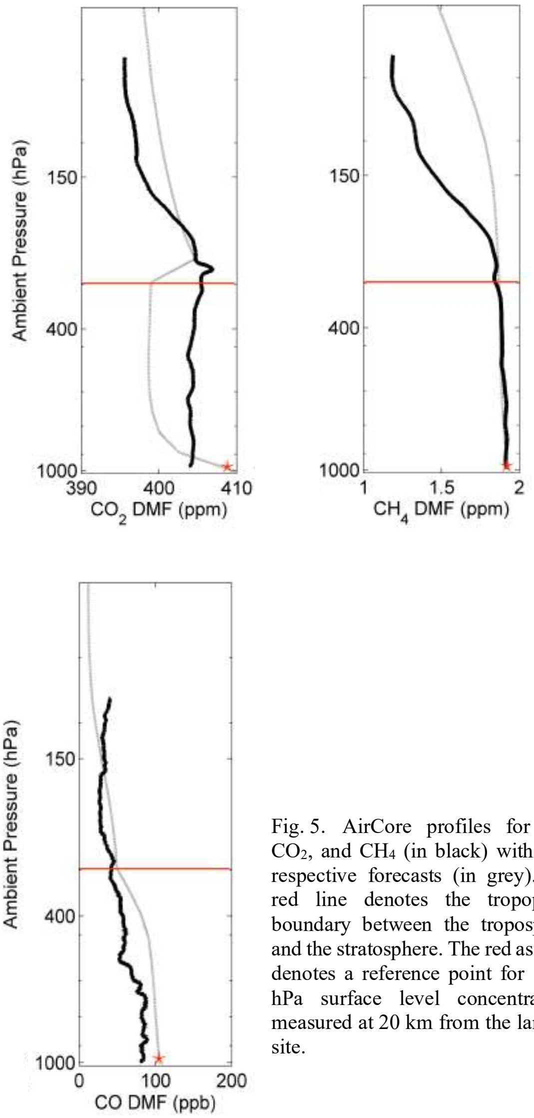

Fig. 5. AirCore profiles for CO, CO_2, and CH_4 (in black) with their respective forecasts (in grey). The red line denotes the tropopause boundary between the troposphere and the stratosphere. The red asterisk denotes a reference point for 1,000 hPa surface level concentrations measured at 20 km from the landing site.

D. Future Work

The AAC and CAC systems were segregated from each other in a two-box design so to enable individual re-flights in future campaigns. Since the BEXUS flight, the AAC has been fitted with its own power supply in order to be independent from the REXUS/BEXUS gondola from where it drew its power. The thermal housekeeping data collected during the flight indicates that the temperature inside the box will remain within operational range of the power supply during the entirety of a similar flight profile. A dedicated power supply also enables easier detection of power related issues such as current limitations. The TUBULAR experiment is ready for a re-flight in order to validate the AAC sampling mechanism. The complete Student Experiment Documentation (SED) is available from [7] and is of interest for any future replication efforts.

Finally, it is worth noting that the hold times of the sampling bags are typically 48 hours [8]. Future iterations of TUBULAR could address this limitation by using "a maneuverable glider or return vehicle for easy recovery in the field" as suggested in [3]. Originally proposed for an AirCore, this idea becomes more feasible considering a lessened mass penalty associated with lightweight sampling bags.

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Educational Test Bench for Attitude Control of 1U Cubesats

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***Abstract*— In this paper, we present a test bench intended to test attitude control of 1U Cubesats. This platform, based in air bearing principle, is intended for educational purposes. It is designed according to the principles of modularity, low costs and usability. We have built the frame and the cubesat model using additive manufacturing techniques. Our design is affordable, easy to reproduce and based in COTS. We also present a basic 1U cubesat frame that fits inside a sphere, allowing a full 360º movement around all axis. The cubesat model is equipped with reaction wheels and manetorquers.**

***Keywords*— cubesat, attitude control, education, Project based learning, opensource**

I. Introduction

A deficiency in the teaching of spacecraft technology is the lack of hands-on practical sessions that quite often rely on computer simulations only. This approach offers to the students a limited understanding of the complexity of the full system and miss some important hardware related aspects such as EMC, limited availability of power, physics time constants, communication latency, manufacturing tolerances, etc. The only way to highlight all this issues is to use real engineering models in practical sessions. However, the use of flight-qualified components for this purpose is limited by its high price, limited availability, lack of documentation and complexity of use. On the other hand, the integration of both open source resources (for software and hardware as well) and COTS (Components Of The Shelve) offers a wide range of possibilities to address this challenge. These resources are available at low price (or even for free!) and are popular among engineering students, so the learning time is really short. This approach is not only useful for educational purposes but for technology demonstrators and validations of actual systems for flight in early stages of development.

Several works follow this line. For instance, in [1] a 1DoF testbench for testing attitude control algorithms of a 1U cubesat with flexible apendages, which represents the deployed solar arrays of the spacecraft. In [2], a reaction wheel assembly is developed from scratch in the frame of a cubesat developed by students. Finaly, [3] shows a similar initiative focused in teaching activities at Master level.

In this paper, we present a test bench intended to test attitude control of 1U cubesats. This work is the result of a final project of double engineering degree (Mechanics and Electronics) conducted in our Faculty and follows the same approach that all abovementioned works. As in [4], we demonstrate that outstanding and high motivated students from other disciplines can successfully develop space related projects.

Although the main purpose of both the test bench and cubesat model is the test of attitude control, we can easily perform many experiments related with other subsystems of the spacecraft, such as power management, communications, control algorithms, software engineering, actuators design, packaging, etc. Moreover, this platform can be easily used to foster educational space related activities among high school students and STEM subjects as well.

This paper is organized as follows. In sections II.A II.B we describe the air bearing and the cubesat model respectively. In section III we suggest some practical sessions that can be conducted with the proposed test bench. Finally, we outline the conclusions and future works.

II. System Description

A. Airbearing Test Bench

It is worth to mention the arrangement of the cubesat under test. Instead of lying on top of a platform with a limited range of movement, as the most common case is [5-6], the cubesat model fits inside a sphere that "floats" on top of the air bearing, as it is shown in Figure 1. This arrangement allows a free rotation of 360º in all axis. However, if it is necessary, we can fit the EUT, a larger cubesat arrangement of 3 or 6 units, on top of a hemisphere, according to the most common arrangement.

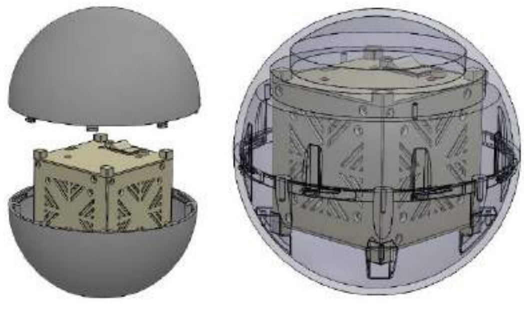

Fig. 1. Cubesat fitted inside the sphere

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We can operate the testbench in three ways. The first one is to fit the 1U cubesat under test inside the sphere, thus allowing a 360º of freedom in all directions, as it has been already mentioned. In this mode, we have the opportunity to test ACS in a complete range of movements. However, we need to balance the sphere in order to compensate uneven mass distribution of the cubesat under test. In the second mode, we can remove one half of the sphere. In this case we have a range of movement limited to 60º of inclination. For instance, this is the configuration that should be used to test suntracking algorithms. Figure 2 illustrates this arrangement. Finally, in case to test a larger spacecraft, we ca attach a solid platform to one of the hemispheres.

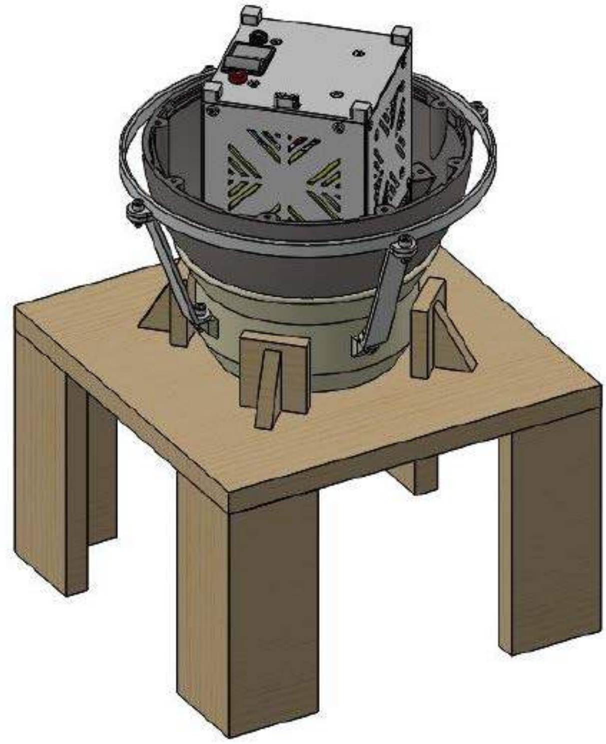

Fig. 2. General view of the test bench. The ring outside the hemisphere limits the movement to 1 DoF

Additionally, we have designed an attachment that reduces testbench DoF to one in order to tune a single controller at once. We have used FlowSimulation-SolidWorks to simulate airflow and the distribution and diameter of holes in the base frame as well [7]. Figure 3 shows a view of the air bearing base.

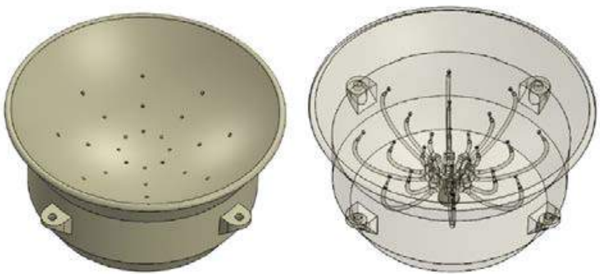

Fig. 3. Detailed view of the base of air bearing and air channels

As we have used plastic materials for the 3D manufacturing process, this testbench is suitable to attach some coils in order to produce a magnetic field and, therefore, test ACS based on magnetorquers.

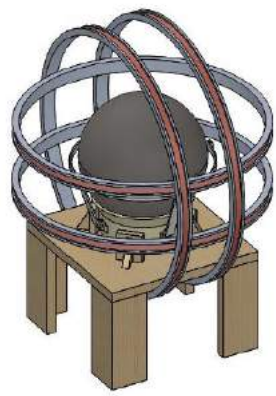

Fig. 4. Test bench with coils to test ACS based on magnetorquers (for the shake of clarity one set of coils are not shown)

B. Cubesat Engineering Model

Moreover, we have designed a 1U cubesat frame using a modular approach, in such a way that it is easy to replace the equipment on board. In this way, you can test flywheels or magnetorquers of both simultaneously. Regarding the cubesat model, Figure 5 shows the basic configuration that consists of 3 flywheels, a 9 DoF Inertial Measurement Unit (accelerometer, gyroscope and magnetometer), a wireless communication board, battery pack and 3 light sensors.

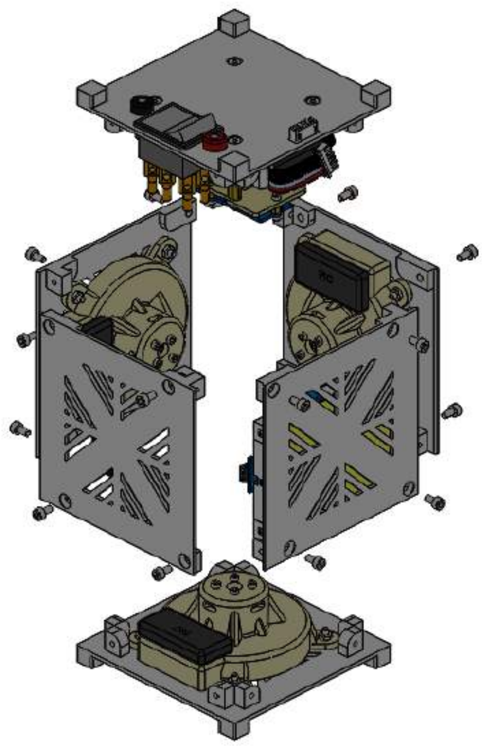

Fig. 5. Exploded view of the cubesat with 3 reaction wheels assemplies, battery pack (upper face) and control board.

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We have also designed some faces of the cubesat equipped with PV arrays. In addition, we have also designed some payloads as cameras or laser pointers. Figures 6, 7 and 8 show a view of the battery pack, an exploded view of the reaction wheel assembly and how it is attached to a cubesat face, respectively.

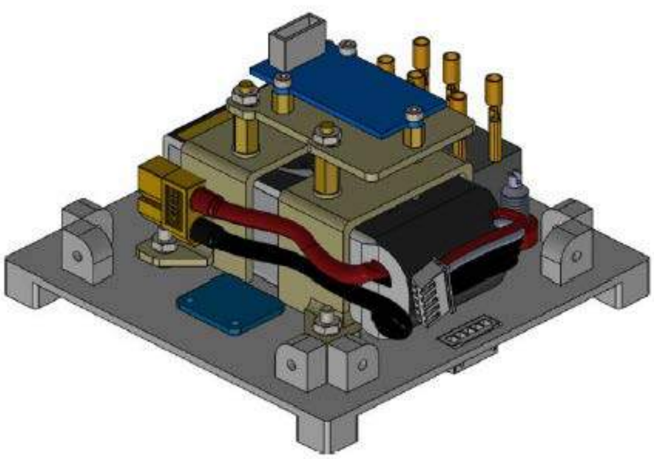

Fig. 6. Detailed view of the battery pack

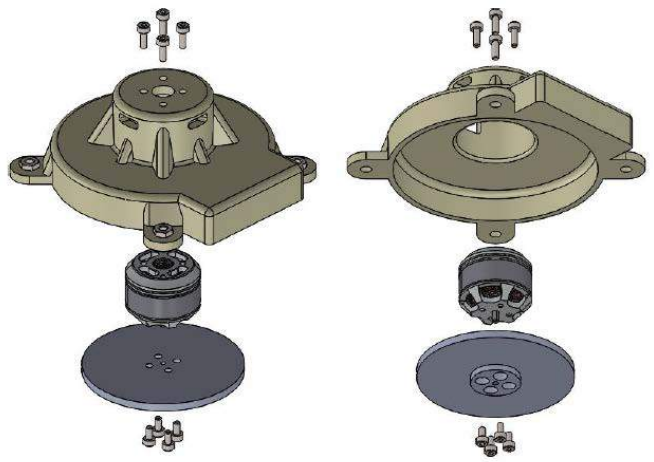

Fig. 7. Detailed view of reaction wheel assembly (brushless motor, inertial mass and housing)

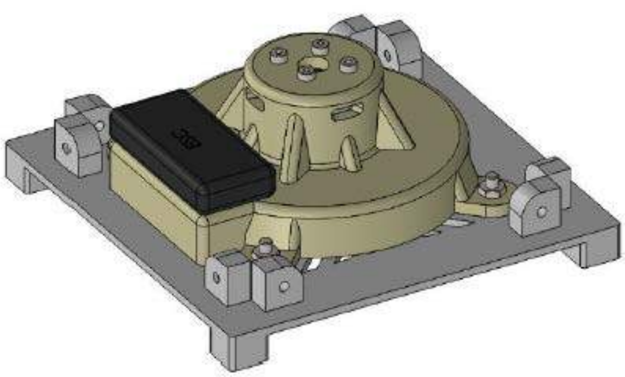

Fig. 8. Full reaction wheel assemply attached to a cubesat face

Figure 9 shows the block diagram of this basic configuration.

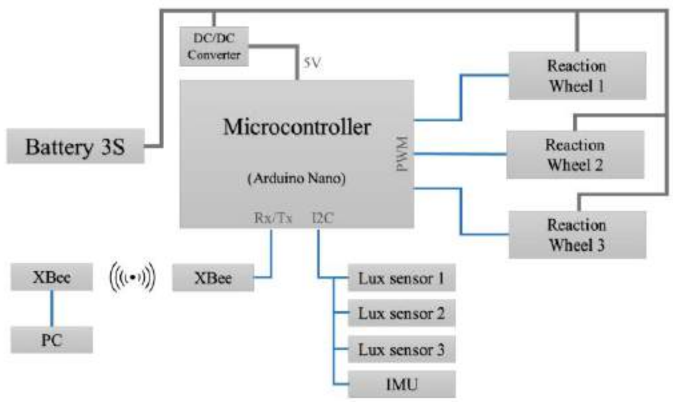

Fig. 9. Block diagram of cubesat engineering model

Table 1 summarizes the main components we have used.

TABLE I. MAIN COMPONENTS

Component	*Qty*	*Features*
Arduino Nano[a]	1	5V ; 16MHz ; 32kB Flash-
TATTU LiPo Battery	1	11,1V ; 3s ; 1550mAh, 45C
MN1806 Brushless motor	3	1400KV
ESC Emax BLHeli	3	-
IMU - MPU 9250	1	I2C, accel, gyro, magnet.
TSL2561, Lux sensor	3	I2C,0.1-40,000lux

III. POSSIBLE PRACTICAL WORKS

In this section, we suggest a set of possible topics that can be studied using this test bench and cubesat model as well. Please, consider this list as a mere suggestion. This list can be enriched by the contributions of the community. With this test bench it is easy to address several basic engineering concepts in different fields such as control, power distribution, communications, mechanical packaging, etc.

A. Control engineering

- Tune a PID controller using the 1 DoF setup
- Compare controllers in terms of different criteria, such as accuracy, power consumption, etc.
- Use different type of controllers (Fuzzy, neural-networks, etc.)
- Use the 3DoF setup to test a full ACS.
- Test ACS for sun tracking.
- Test ACS in the conditions considered [1]

B. Power management

- Test different MPPT (Maximum Power Point Tracking) algorithms for solar arrays.
- Test several power distribution architectures.
- Evaluate the combined performance of sun tracking and MPPT algorithms in terms of energy harvest.

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C. Communications & Data Mangement

- Impact of a communications latency in spacecraft performance

D. Mechanics

- Impact of tolerance on mechanic performance of the ACS
- Optimization of reaction wheel assembly

IV. Conclusions

In this paper we have presented a testbed based in the air-bearing principle intended for the test of Attitude Control System of 1U cubesats. In addition, we also present an engineering basic model of cubesat that allows the development of a wide variety of hand-on projects. We have used additive manufacturing techniques for mechanical parts, COTS for electronics hardware and open source software. This set is affordable and modular and it can be used for teaching purposes in universities at degree or master level or for STEAM activities in high school as well.

In future works, we want to develop a simulation model of the systems in order to correlate actual behavior and simulation results and thus, highlight the existence of "non-ideal" behavior that are intrinsic to actual systems.

Acknowledgment

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Quad-spectral Unaided Experimental Scanner of Topography on BEXUS 27

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***Abstract*—This paper describes the REXUS/BEXUS experiment for Quad-spectral Unaided Experimental Scanner of Topography (QUEST). QUEST as part of the REXUS/BEXUS program was designed, developed, built, tested and operated by a team of 17 students from different German universities. It scanned the planet surface by analysing an array of four light sensors (RGB and IR) and two spectrometers. A reusable cluster algorithm determined autonomously onboard an overview image of the surface with marked areas depending on the type of the surface. Furthermore, the algorithm's data base was generated and optimized before and during flight. Regarding the hardware a modular sensor framework with standardized interfaces was implemented. The project has been a successful step to the designated target to build an autonomous system which could be used in interplanetary missions with demanding constraints on the bandwidth.**

Keywords—Autonomous; Topography Scanner; REXUS/BEXUS

I. INTRODUCTION

A key feature of interplanetary satellite missions is the analysis of the planet surface. Therefor many different sensors are used to get a detailed overview. Nevertheless, the bandwidth for transferring the measurements is limited in a satellite mission. Thus, autonomous evaluation and election of valuable information on board of the satellite is required to reduce the resulting data size. There are several kinds of observations made by satellites from the surface of a planet. An interesting research area is the categorization of distinct areas on the surface. However, new algorithms to perform this kind of research are rare. The overall purpose of this experiment is to contribute to landscape categorization based on satellite imaging with a focus on the requirements of interplanetary missions. These requirements are reflected in a modular system made for reusability and result in a testbed for a newly developed algorithm for landscape distinction based on cluster analysis of distinct sensor and camera measurements. The Quad-spectral Unaided Experimental Scanner of Topography (QUEST) mission is based on the following primary scientific objectives:

- Development of a modular sensor framework
- Taking pictures of the earth in different wavelengths
- Differentiation of landscapes based on taken images
- Onboard data analysis

II. EXPERIMENT DESCRIPTION

A. *Experiment Concept*

To properly categorize the landscape the algorithm needs a set of predefined data. Therefore, it is necessary to obtain reference data with the given sensors and cameras to calibrate the algorithm. This raw data was collected in previous experiments on the ground, the ascent phase of the balloon and while the final experiment on the balloon is running. After the raw data is collected some areas are categorized by hand. Therefor an easy to use calibration software is produced and integrated in the ground station. This algorithm does not restrict the number and kinds of sensors and cameras. An ordinary RGB camera, an IR camera and a spectrometer are used. Those sensors are giving us the possibility to distinguish between snow, vegetation, water, rocks and overlaying clouds. To keep the possibility for late sensor switches an open modular sensor framework is designed as shown in Fig. 1.

Every sensor is coupled to a pre-processing unit to provide clearly defined data on a common data bus for all sensors. The data is requested by the main processor and fed to the algorithm. The result is stored and periodically send to the ground station. Additionally, data logging is performed and stored for post experiment analysis of the system behaviour.

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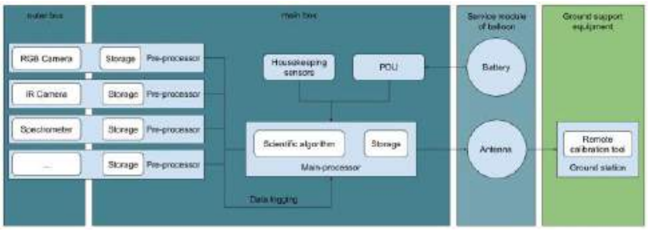

Fig. 1. Experiment Concept

B. Machnics Design

The experiment is composed of two main units; on the first hand the sensor box, which is located outside of the gondola containing all the sensors, cameras and the corresponding pre-processors. On the other hand, the gondola box, which contains the power distribution, the main processor and serves as the link between the gondola and the experiment. The shifted sensor box is necessary to provide an unobstructed field of view downwards. The whole box has a dimension of 821 x 280 x 380mm and a mass of 8.5kg. The experiment is not significantly optimized in aspect of volume or mass.

Since the thermal environment on a high-altitude balloon mission is very harsh a proper thermal control was implemented. For this purpose, several heat sinks were mounted onto the processors and power converter to prevent the system from overheating. Furthermore, thermal insulation in form of high-density polyethylene was integrated. Also, an active thermal control system was integrated to prevent the spectrometer from freezing, which is the most thermal sensitive part.

C. Electronics Design

The experiment unit consists of nine components, separated in inner and outer components. On the outside there is the sensor box including two near infrared cameras, two visual light cameras and two mini spectrometers. The cameras are paired with a pre-processing unit including a GUMSTIX IceStorm board. For the cameras a redundant design is used to collect more data and increase reliability.

Inside the gondola there are the other electronic components: pre-processing boards for the spectrometers, the Onboard Computer (OBC) and the Power Distribution Unit (PDU). The PDU provides for the whole system which runs on two different voltage levels. It converts the provided battery power to the necessary 3.3V and 5V. As mentioned in the mechanical section a thermal control system is attached to the spectrometer. Also, a housekeeping system is integrated to get a real-time overview of the system during flight.

Fig. 2. Mechanical Design

In Fig. 3 you can see a concept overview of all components including the cable connections. The PDU supplies the power to each system via a dedicated connector.

D. Software Design

The software is as designed modular which leads to a high interchangeability of the different components for example switching between different algorithm types. Furthermore, the software is divided into three main parts listed below and visualized in Fig. 4.

1. **Sensors**: Handling data acquisition, pre-processing and transmission to OBC. For a consistent programming effort and communication, a framework must be designed.
2. **Main processor:** Central part with need to design an interface for an easy use of distinct algorithms.
3. **On Board Data Handler**: Responsible for tracking data and communicating with the ground station. Is not part of the framework, but essential for the experiment as it is responsible for ground communication and data storage.

In general, the design can handle partly system failures.

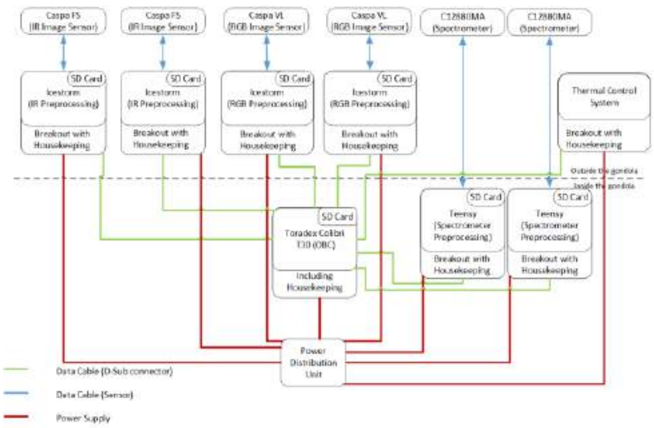

Fig. 3. Electronic Component Overview

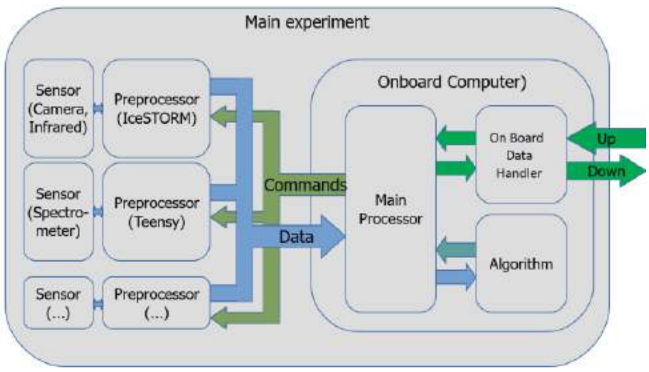

Fig. 4. Software Design

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This means in case of an error on a pre-processor the main processor works with the remaining pre-processors. If the lost pre-processor recovers itself, the data will be used again on the main processor. Furthermore, in case of a main-processor failure each subsystem stores its data locally which means on later postflight analysis the data can be recovered and analysed.

III. Scientific ALGORITHM

The central feature of the project is the algorithm. In interplanetary satellite missions one of the most important subjects is the analysis of planet surfaces. Therefor many different sensors are used to get a detailed overview. Nevertheless, the bandwidth for transferring the measurements is limited on a satellite mission. Thus, autonomous evaluation and selection of valuable information onboard of the satellite is required to reduce the resulting data size. Nevertheless, new algorithms to perform this kind of research are rare. Therefore, a new algorithm was developed by the team. The goal was to reduce the amount of data which has to be transmitted and still get detailed knowledge of the surface structure. On earth it would be the differentiation of landscapes, such as water, forest, and acreage and fields. QUEST on BEXUS 27 was the first test flight of this new surface analysis algorithm which can be sketched as followed.

1. The inputs of the algorithm are clearly defined sensor and camera measurements for a given region of the planet surface.
2. These regions are split into small fragments for example the pixels of an image sensor.
3. Then an n-dimensional cluster analysis is performed which groups data points together which have nearly the same coordinates and sensor values. n is composed of the number of coordinate-axis and the number of distinct sensor measurements for that fragment.
4. The algorithm calculates the mean and standard deviation for each type of sensor value for each cluster
5. in the next step.
6. These values are compared to the reference values which were prepared beforehand, and the most likely category is assigned together with the accuracy to the single points of the cluster.
7. In the last step the clusters are written back in a result image.

As cluster algorithm is used the DBScan algorithm, which works well on high dimensional data sets. See [1] for more information on the algorithm and [2] for more information on the algorithm in multidimensional data sets.

IV. GROUND SUPPORT EQUIPMENT

A. *Ground Support Unit*

For controlling the experiment two tools were developed called the ground support equipment. The Ground Support Unit (GSU) is one part and responsible for the communication between the experiment and the ground. Also, it enables an overview of the system during flight, showing the connection status, allowing to send commands and receive all data, updating the algorithm, see raw data and result images after on board processing.

B. *Scientific Support Unit*

The Scientific Support Unit (SSU), shown in Fig. 5, the ground control team can select different clusters in multiple sensor images and classify them with labels. This manually classified data is used to create parameters for the algorithm on board, as well as a database that the algorithm uses for classification, which will be sent to the experiment with the help of the GSU and telecommands. The functionality of the SSU can be described as followed. The SSU allows to overlay images from different sensors of the same image set. A set contains images from multiple sensors that were shot at the same time. The opacity of each image of the set can be controlled individually. The images are shown behind a canvas, which allows to manually draw clusters on top of the images as well as configure the classification of the clusters by drawing with colours for different features. Furthermore, the cluster algorithm can be executed locally on the computer by the SSU to identify clusters which can be assigned to a feature.

V. FLIGHT ANALYSIS

During the ascent phase raw images were collected and sent to the ground to update the already existing database, which then was uploaded. The raw images were analysed with the SSU to improve the database continuously. As expected, the predicted features got more and more precise over time. Furthermore, a new integration of a completely new feature was possible during flight. This improved the results, but the final classification at the end of the flight was still improvable which was done during post flight analysis. In general, all components worked as planned. The pre-processors filtered the incoming data to get synchronized and standardized pictures. The communication between the subsystem worked almost fine and all data was stored for later analysis.

A. *Image Results*

During the flight, a total of 54 raw RGB image and 54 raw infrared images were downloaded to the ground station. These recorded images are undersaturated and have a round border from the filters of the cameras. The RGB cameras also had a

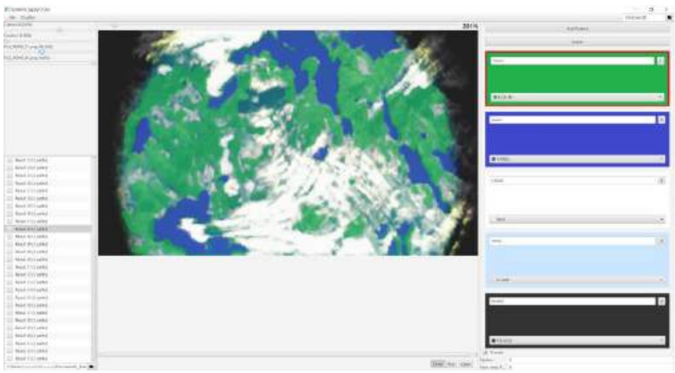

Fig. 5. Scientific Support Unit

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slight offset to the infrared cameras, resulting in a translated image. The original images are shown in Fig. 6 and Fig. 7. As expected, the first in flight result images were not satisfying. The by the algorithm yielded clusters were too large and the classification was done incorrectly.

Updates to the parameters of the clustering algorithm as well as updates on classification database improved the quality of the results. This led to a great improvement towards the end of the flight. Still at the end of the flight most clusters were classified incorrectly as a result of the undersaturated images. To increase the quality of the images, a filter and a translation was added during post flight analysis to remedy the effects of the misconfigured cameras. The results of this post processing can be seen in the Fig. 8 and Fig. 9. With the improved images and the improved classification database during the post flight analysis, the algorithm classified the clusters with very few wrong classifications as shown in Fig. 10. The example result classifies the following features:

- Water
- Forest
- Acreage and fields.
- Border of the image
- Unclassified

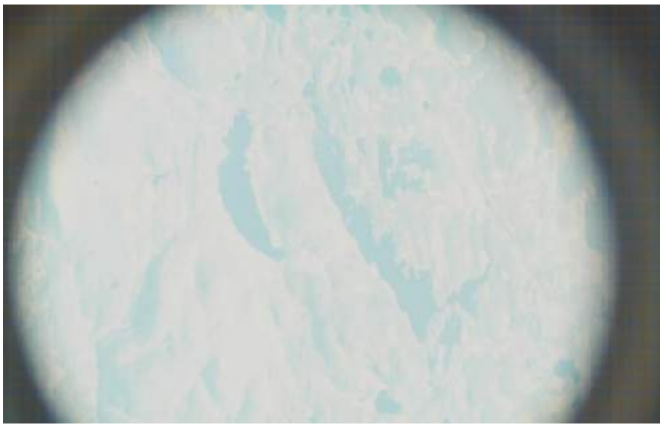

Fig. 6. In flight original RGB image

Fig. 7. In flight original infrared image

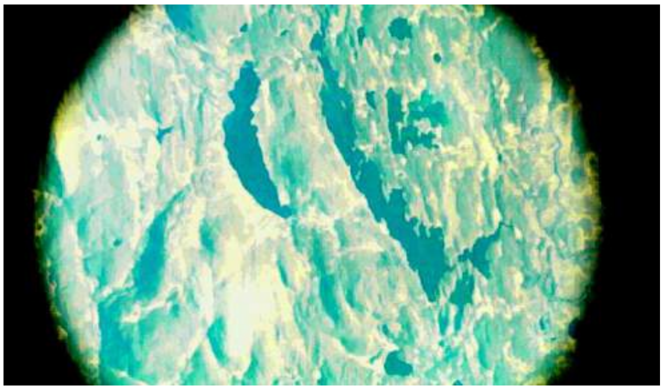

Fig. 8. Post flight optimized RGB image

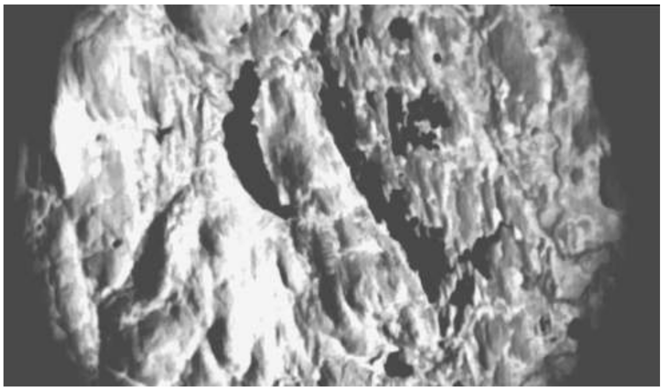

Fig. 9. Post flight optimized RGB image

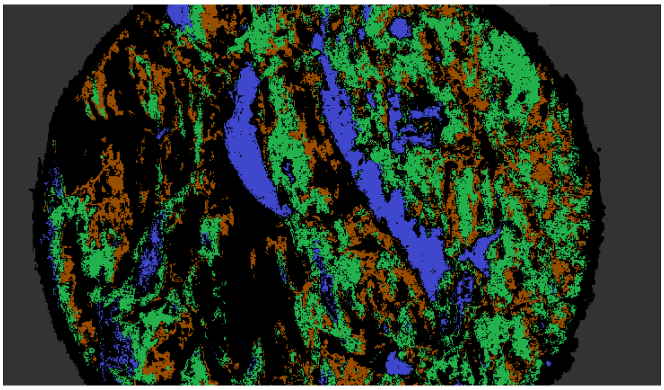

Fig. 10. Result image based on post flight optimized raw images

B. Data Transmission Analysis

The final data amount is reduced by minimizing the possible values for each pixel of the result image to the number of categorized features. Therefore, the value range for each pixel gets reduced from 256 to the number of features, which are in our case five. This means the needed storage per bit is reduced to only three bits instead of eight bits. Compression the onboard analysis reduces the amount of data even furher. This leads to a reduction of data per result image to 1-20 percentage of the original data, for one sensor. For multiple sensors and higher resolution, the data amount is reduced linear, since instead of all the different source images only one result image must be sent. For four image sensors it is at the maximum 5% of the original data amount. Furthermore, the uplink for an

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algorithm database is very small. This absolutely fulfils the goal of reducing the amount of data which is produced and must be sent to earth.

VI. Lessons Learned

A. System testing and verification

A lot of time was spent testing all systems in private. In the end the time ran short for complete system tests. It was more difficult to solve the found issues, when combining the subsystems to one big system. For example, there were issues with the pre-processors: They work absolutely fine as single system communication as well as image reception and processing. After integrating these subsystems and activating the image sensors, the communication ran unreliable. In the end some pre-processors had issues with handling both. Probably due to manufacturing difficulties. It turned out that the time schedule for tests after combination of subsystems was too short. Especially, the time for solving all issues. Therefore, it is important to save enough time for testing the complete system. Also, the dark rim on the images and the undersaturated images could have been avoided with more extensive tests after full integration.

B. Issue priorities

Due to trying to solve a compression issue other tests were done more inaccurate. Unfortunate, other issues were detected afterwards, which could have been solved better. Focusing on the compression issue took time, which could have been used to solve problems, which would have revealed more benefits with smaller effort. This means even while solving last errors in the system it should not be forgotten to set the correct priorities. Even if almost all issues are solved.

C. General educational benefits

The project was performed by a team of 17 students in parallel to their bachelor studies. As foundation for the project conduced the knowledge gained from university courses. The REXUS/BEXUS program enabled the possibility to gain practical experience while realising a whole real space project. The theoretical content within the university courses found an application during the studies. All the theoretical things about spacecraft system design, modularity, redundancy, single point of failure, verification, testing, etc. lead to a deeper understanding and importance of different fields. Moreover, the students were able to design their own system working in their own fields of interest no matter if it is team management, constructing and planning a hardware design or dive into recent computer science research areas such as data mining and knowledge-based system. Most importantly a lot was learned about working in a team and completing a project including reviews, tests and a launch campaign.

VII. Conclusion

Summarized the project can be described successful in the main objectives. The system was very agile to changes and had no problems with loss of sensors, which appeared during flight and testing, or other failures in different system parts. The modular concept also provided big advantages for solving problems with sensors or pre-processors. Switching to a spare part was possible with very less effort. Also, the experiment itself worked fine. The pre-processing, the system control, and the algorithm worked very fine onboard during flight. Also, the onboard differentiation of landscapes worked, but due to the sensor problems the onboard results were not really satisfying.

Fortunately, with extensive post flight analysis the algorithm results were good and the concept as whole is proved to work. After this first concept approval the sensor diversity can be increased, the power usage reduced, and the processing speed enhanced. All in all, the team learned a lot, was able to test the concept successfully and gathered important experiences.

Acknowledgment

This research project was supported by the REXUS/BEXUS program. The QUEST team is proud to be part of this program, enjoyed all the workshops a lot and is grateful to have flown on the BEXUS 27 mission in October 2018 from the Esrange Space Center. The REXUS/BEXUS program is realized under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through the collaboration with the European Space Agency (ESA). Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project. EuroLaunch, the cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. The authors also wish to thank the endorsing professor H. Kayal (University of Würzburg) and the companies that provided technical and financial support to the experiment team: Mouser Electronics, Inc., Texas Instruments, Inc., Thorlabs Gmbh, ZARGES Gmbh, Leica Geosystems AG, and µduino.

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From Space to School – Earth and Moon Observation in Immersion and Experiments

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***Abstract*— To support the primary and secondary STEM education in Germany, the European Space Education Resource Office (ESERO) Germany was founded in May 2018. It was implemented by a consortium of ten institutions led by the Geomatics Research Group at the Department of Geography at the Ruhr-University Bochum, working in close collaboration with ESA Education (funding institution) and the German Aerospace Centre (DLR). Institutes of the University of Bonn, Cologne and of the Ruhr-University Bochum as well as the Planetarium, the Observatory Bochum and the network "Zukunft durch Innovation" are part of the consortium. During the so-called "Phase Study 0" the German educational system was analysed and a strategy to support STEM education in Germany was worked out. In comparison to other European countries, the educational system in Germany is structured by the states and not by the federal government. Thus, each of the 16 states decides on how to structure their educational system, which leads to multiple differences and a sum of nearly 450 different curricula in the STEM subjects. A strategy was needed to reach teachers and pupils in all federal states equally and motivate pupils for STEM subject. Therefore, a quantitative curriculum analysis was conducted by mapping the state curricula across the primary and secondary school education levels. As a result, ESERO Germany will focus on the competence orientation of STEM subjects and on the topics of the STEM curricula combined with applied space science. This is shown in our examples, three teaching units as part of ESA's *Moon Camp Challenge* and our designed Massive Open Online Courses (MOOC's) about Earth. These short videos combine geographic analysis and physical background information at the same time. Also, we present our Augmented Reality Application "From the Earth to the Moon and Back". The paper finishes with a short outlook on upcoming teacher trainings, competitions and classroom resources.**

Keywords*— *education, earth observation, moon, classroom resources

I. INTRODUCTION

The European Space Education Resource Office (ESERO) Germany was funded in May 2018 in close collaboration with the European Space Agency (ESA) and the German Aerospace Center (DLR). The Geomatics Research Group at the Department of Geography of the Ruhr-University Bochum (RUB) leads the consortium of ten institutions. Furthermore, the consortium consists of the Zeiss Planetarium Bochum, the Chair of Astronomy at RUB, Bochum Observatory, the University of Bonn with the Remote Sensing Research Group at the Department of Geography, the Hausdorff Center for Mathematics, the Physics Institute, and the Argelander-Institute of Astronomy as well as the Institute of Physics Education at the University of Cologne and the well-known network

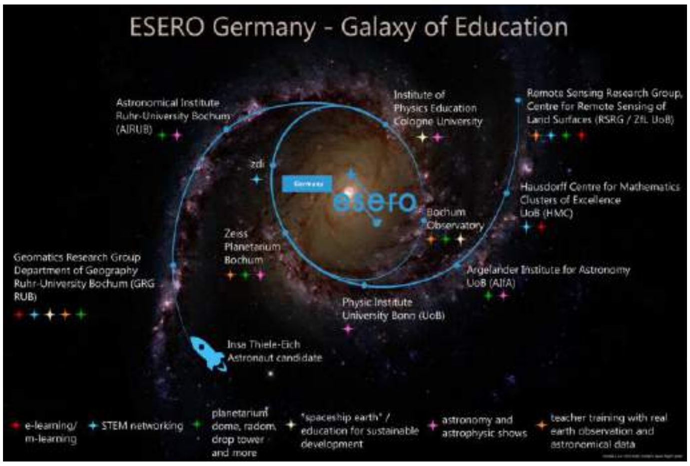

Fig. 1. The Galaxy of Education showing the ESERO Germany consortium and their different tasks.

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"zdi.NRW – Zukunft durch Innovation" ("Shaping the future through innovation") (Fig. 1). The goal of ESERO Germany is to support the German STEM education by using the fascination of space to motivate and encourage both students and teachers. Therefore, classroom resources, teacher trainings and events are implemented regarding topics of applied space science such as earth observation, astronomy, navigation, communication, and exploration.

The paper presents the results of the so-called "Phase 0 Study" where the core curricula of STEM subjects were analysed, experts on education interviewed, and space professionals approached. A thorough mapping of the state curricula across the primary and secondary school education levels in Germany has been conducted, needs and potential areas of priority intervention were identified, and the role of space-related resources and activities in meeting these needs were assessed. Hence, it was possible to make recommendations for classroom resources and activities.

Our designed Massive Open Online Courses (MOOCs) about Earth Observation are an example of a classroom resource that can be used in different subjects and contexts and is therefore usable in the heterogeneous curricula. Additionally, resources for ESA's *Moon Camp Challenge* and Augmented Reality Apps dealing with the gravitation of the Earth-Moon system are depicted.

II. The German Educational System

In the school year 2017/2018, the German school educational landscape was shaped by 8,346,707 pupils taught by 679,478 teachers at 37,121 schools in 16 federal states [1]. The German educational system is not structured by the federal government, but by the states. Thus, each state government can decide on how to structure their educational system [3]. This results in multiple differences between the federal states. This chapter gives an overview of the educational system focusing on the primary and secondary education (Fig. 2).

A. Primary Education

With the start of compulsory schooling the child enters primary education, meaning the time spent at primary school, which amounts to either four (e.g. North Rhine-Westphalia) or six (e.g. Berlin) years [3]. The main subjects are German, mathematics and general science ("Sachunterricht"). In addition, subjects such as a foreign language e.g. English, arts and physical education are taught. At the end of the primary education, a recommendation for a specific type of school is given [3]. It is based on former grades and will influence the following educational career .

B. Secondary Education

Primary education is followed by the lower secondary education, which is divided into different types of schools or holds different educational programmes [3]. The *Hauptschule*, *Realschule* and *Gymnasium* each aim for a specific type of school-leaving certificate (secondary modern school qualification, general certificate of secondary education, or Abitur, which is the equivalent to the British A level), that is usually gained after nine, ten, or twelve years, respectively. At

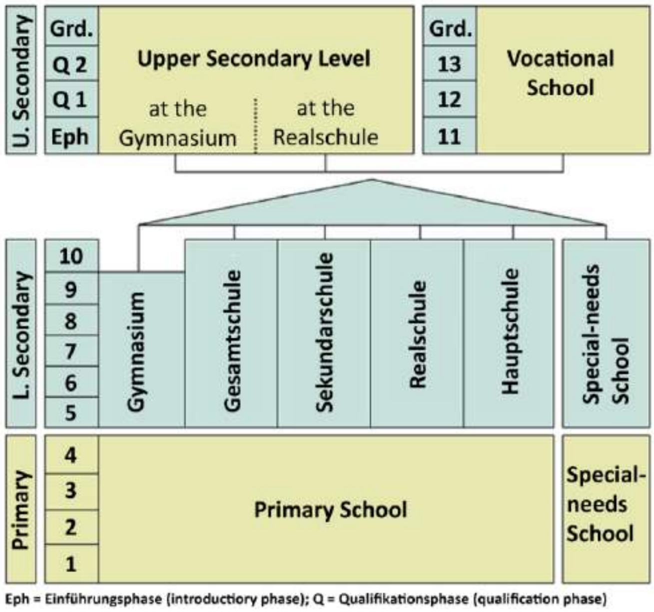

Fig. 2. Overview of the German educational system [2]. Eph = "Einführungsphase" (introdutory phase); Q = "Qualifikationsphase" (qualification phase). The German school system is divided into primary (1 – 4th/6th grade), lower secondary (5th/7th – 9th/10th grade) and the upper secondary education (10th/11th – 12th/13th grade). It is possible to enter the upper secondary Education after the 9th grade at the Gymnasium ("G8") or 10th grade ("G9"). The major school types are: *Grundschule* (primary school), *Gymnasium* (grammar school), *Gesamtschule* (comprehensive school), *Hauptschule*, *Realschule* and *Sekundarschule* as secondary school and special-needs school.

Gesamtschulen, students do not follow one specific educational career from the start but rather participate in classes with different levels of difficulty. The general education school-leaving certificate can be obtained at all secondary schools. This certificate qualifies the graduate to enter the upper secondary level. *Gymnasium*, *Realschulen* and full-time vocational schools and dual vocational trainings are all part of the upper secondary education [3]. The choice of the educational institution depends on the former school-leaving certificate.

This education level includes the following STEM-subjects: mathematics, computer science, biology, chemistry, physics, technology, and geography. In some curricula the subjects of biology, chemistry, and physics are treated as general science in the lower secondary level. The amount of curricula for these seven subjects in 16 federal states and the four different school types is approximately 448 – excluding primary schools and upper secondary classes!

III. Methodology of the Quantitative Curriculum Analysis

The German educational system is complex and the topics and requirements for didactic material is different in each federal state. Hence, a well-conceived strategy was needed to handle the broad spectra of STEM curricula in Germany. Therefore, we had a close look at the national educational standards in order to detect congruities and similarities between

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the STEM subjects across the state borders. The analysis of secondary (lower and upper) education curricula was conducted for the STEM subjects of mathematics, computer science, biology, chemistry, physics, technology, geography and general science. Exemplary, the curricula of the *Gymnasium*, *Gesamtschule*, *Realschule* and *Hauptschule* were examined. For the primary education, the subjects general studies and mathematics were analysed. Not only contents, but also contexts were noted.

In addition, qualitative expert interviews were conducted, to get a deeper insight into the possibilities of implementing space-related topics, astronomy or astrophysics in schools. Our current and future activities are based on this curriculum analysis, the expert interviews and consultation of space education expert from the European Space Agency (ESA) and the German Aerospace Center (DLR). All results are combined in the so-called “Phase 0 Study”.

IV. Results

A. *Educational Standards for STEM subjects and competence orientation*

To standardize the competencies of pupils upon the completion of primary education (4^{th} grade), lower secondary education (10^{th} grade) and the general higher education qualification entrance (“Abitur”) national educational standards for the mathematics, physics, chemistry, biology and languages were developed in Germany. In addition to these educational standards [4, 5, 6, 7], several associations propose further standards in the fields of informatics [8], technology [9] and geography [10] to complete the STEM subjects.

Tab. 1 presents the competencies for the most relevant STEM subjects in Germany. The colums represent the subjects and the lines describe the different competencies for this subject. Merged lines show competencies that are needed in more than one subject. The subject of technology has a special position as it can act as a link between all subjects. The competencies in the field of technology include the *usage*, the *comprehension* and the *construction of technical components* in diverse fields of actions like transport and traffic or information and communication. In Germany, technical subjects can be found under a variety of names (e.g. "work, economy, technology” or “work science”). Since the integration into the curriculum of neither technology nor informatics is mandatory, the conveyance of technical competencies and computer skills is rather difficult. Thanks to the diverse applicability of technical devices, an integration of these competencies into lessons is certainly possible.

The competence of *communication* is seen to be taught in all subjects. Pupils ought to communicate subject-related contents correctly and exchange information with one another. In the case of maths, this means that the facts are considered mathematically.

Another competence in the subjects of biology, chemistry and physics is the *acquisition of knowledge*. This particularly includes the planning, execution and evaluation of experiments. Quite similar is the competence *apply methods* in the subject of geography. The pupils should develop the ability to gain and

TABLE I. THE COMPETENCIES FOR THE MAIN STEM SUBJECTS OF MATHEMATICS, INFORMATICS, PHYSICS, BIOLOGY, CHEMISTRY, AND GEOGRAPHY AND TECHNOLOGY (LOWEST COLUMN). THE REFERENCES FOR THE SUBJECTS ARE MATHEMATICS [4], INFORMATICS [8], PHYSICS [5], BIOLOGY [7], CHEMISTRY [6], GEOGRAPHY [10], AND TECHNOLOGY [9]. TECHNOLOGY TAKES OVER A SPECIAL PART AS IT CAN BE COMBINED WITH ALL OTHER SUBJECTS. ALL COMPETENCIES ARE INTERESTING TO ADDRESS IN THE CLASSROOM RESOURCES.

<table>
<tr><th>Math</th><th>Informatics</th><th>Physics</th><th>Biology</th><th>Chemistry</th><th>Geography</th></tr>
<tr><td colspan="6">communication</td></tr>
<tr><td>argue mathe-mati-cally</td><td colspan="5">reason/evaluate</td></tr>
<tr><td></td><td colspan="5">expertise</td></tr>
<tr><td colspan="2"></td><td colspan="3">acquisition of knowledge (experiment)</td><td>apply methods</td></tr>
<tr><td colspan="2">use and interpret visualizations</td><td colspan="3" rowspan="3"></td><td></td></tr>
<tr><td colspan="2">modelling</td><td>action</td></tr>
<tr><td>deal with formal and sym-bolic ele-ments of maths</td><td>structure and connect</td><td>spatial orientation</td></tr>
<tr><td colspan="2">Technology</td><td colspan="2">utilize</td><td colspan="2">construct/produce</td></tr>
</table>

evaluate relevant information from different media. Another component is the *spatial orientation* and the usage of maps. Based on identified problems, the pupils should develop strategies of *action* that suit the natural and social environment. Especially the use of satellite images can increase methodological skills. This does not only apply to the subject of geography, but also chemistry and biology.

The subjects of math and informatics comprise similar competencies. The *use and interpretation of visualizations* is part of both subjects. The pupils ought to develop, understand and use models. In the subject of informatics, the pupils learn how to *structure and pointedly connect coherences*.

All competencies are interesting to address in the classroom resources.

B. *Recommendations for didactics material*

There is a general consent that interdisciplinary and subject specific learning is supposed to arouse and deepen the curiosity, interests and inclinations of the students. It is very noticeable that the field of natural phenomena occurs in almost all curricula. The offering of space-related topics adds value by fascinating pupils early on and by providing easily applicable materials for teachers. The competency model for the subjects

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of math, physics, informatics, technology, biology, chemistry and geography allows the integration of space-related topics and content into tuition regardless of the federal state. As the materials focus on the competencies to be taught, it is possible to integrate them into lessons in many federal states and school types. The thematic relation to space serves as a means to an end, whereby the applicability increases.

It is necessary to create and adapt existing educational resources based on a didactic concept addressing independent working, discovery-based learning and propaedeutic learning [11, 12]. The materials should be, if possible, in conformity with the general curricula. To achieve this, the material should be structured in a modular way and flexible at use regarding the student's competencies, grade and school type. This can be supported by having the possibility to edit the material and customize it for the individual needs of the learning group. The tasks should be short enough to split the whole material into smaller packages, which can be used flexible in the different length of the lessons. Each of the material should provide a didactic note with tips and recommendation for a use in the classroom.

This holds true for primary as well as secondary materials. The main difference will be a stronger emphasis on instructions in the primary education resources.

To motivate students for STEM subjects, a focus on topics of applied space science like earth observation, space travel, (exo-) planetary research, astronomy/astrophysics, GNSS-Navigation, satellite communication, space technology in everyday life is recommended.

Possible topics for mathematics are for example the analysis and classification of geometric objects and statistical analysis. In geography the possibilities are huge especially in combination with Earth Observation and Remote Sensing. There are also several possibilities in chemistry: energy storage systems or plastics.

V. Examples

Since the ESERO Germany opening ceremony in May 2018 a lot of different classroom resources were produced. In the following, some examples are given. All material can be found on www.esero.de.

A. Experimental Learning

An example for modular classroom resources regarding space technology and science are developed by ESA Education and part of the *Teach with Space* material. Five worksheets [13, 14, 15, 16, 17] have been translated and adapted into German to support the *Moon Camp Challenge.* The tasks of this challenge is to design a 3D model of a moon camp by using 3D-modelling software. The translated material reaches from planning and designing a lunar lander [15] to building a shelter [16] and bionic hands [14]. By filtering "lunar ice cores" (dirty ice cubes) [17] and learning about edible plants in space [13] the students are discussing the dangers and possibilities of the Moon. In addition, the material provides background information and several interesting links for teachers. The resources can be used interdisciplinary and can be split up between the lessons or even parts can be done as a homework. Because of that, the resources can be used flexible and individually in the German classroom. The material is suitable for students from 6 to 10 years [13] 8 to 12 years [14, 16, 17] and 14 to 16 years [15] which suits both primary and lower secondary education in Germany. Also, the material can be used independently from the competition when referring to the Moon and the 50th anniversary of the Moon Landing.

B. MiniMOOCs about Earth Observation

Other classroom resources are Mini Massive Open Online Courses (MiniMOOC) about Earth Observation and Remote Sensing (RS). The material was produced during the project "Fernerkundung in Schulen", which is also located at the Departement of Geography of the Ruhr-University Bochum. This material consists of short videos (4 to 6 minutes long) about different subtopics of Earth Observation and its physical background. The videos can be used as a stand-alone or combined and interdisciplinary to introduce a topic or technique in the lessons. Currently six MOOC's are available on the ESERO Germany website. When using them as a series, the first MiniMOOC ("Images from Space") is an introduction to Remote Sensing and RS satellites e.g. Sentinel 2 or Meteosat. The following videos describe the electromagnetic spectrum ("The Electromagnetic Spectrum –part 1" and "The Electromagnetic Spectrum – part 2") in two parts. After that, the students get an insight in the usage of infrared imagery ("The world in infrared"). "The spectral resolution" and the "spatial resolution" and the different satellites are discussed in the last recently published MiniMOOCs. All videos can be downloaded for free and are also available with English subtitles on www.esero.de/post/413 .

C. Augmented Reality Application: From Earth to Moon

The project "Columbus Eye – Live-Bilder von der ISS im Schulunterricht" and its successor "KEPLER ISS" are based at the Department of Geography of the Ruhr-University Bochum and create interactive and digital learning material. The latest Augmented Reality Application, "From the Earth to the Moon and Back" deals with the gravitational system of the Earth and the Moon. The students can use their phone to turn it into the Moon and changing the distance to the Earth on their worksheets. The real distance is shown on the screen. Additionally, the students can investigate the change of the maximum and minimum tides level in the German Bight on a true-colour Sentinel-2 image. This classroom resource can be used in the 11th grade (16 to 17 years) physics class. The material consists of the worksheets, the tasks' solution and some background information. By using the Augmented Reality App the comprehension and motivation for STEM subjects of the students is increasing [18]. The lack of IT infras tructure in schools can be covered by using the students' smartphone. This material is available for free in German and in English on www.esero.de/post/160.

VI. Conclusion and Future Work

In the German educational system the curriculum is given by the federal states. In combination with the different school types, the number of curricula for the STEM subject is high. To

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produce classroom resources that can be used in all federal states the European Space Education Resource Office (ESERO) Germany conducted a curriculum analysis by mapping the core curricula and identifying the potential areas and didactic focus. Competence orientation and a thematic focus on applied space science topics is key to produce flexible and usable material. The material should be modular to use it in different grades and difficulties. By addressing independent working, inquiry-based learning and propaedeutic learning in the classroom resources the pupils' competencies will be strengthened and their motivation for STEM subjects increased [11, 12]. Besides having material in conformity with the curricula, it should be structured in a modular way, editable and flexible at use in the classroom.

Different teaching materials have been produced by ESERO Germany since the opening in May 2018. These materials are available for free on the website and support Earth Observation activities and competitions by the European Space Agency.

In the future, a focus will lie on Space Exploration and Earth Observation. Many more resources by ESA Education will be translated and adapted into German. Also, teaching material supporting the exhibition *INNOspaceExpo* is planned. The development of material is accompanied by teacher trainings focussing on gaining basic knowledge and exploring the variety of material.

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Three Editions of Inter-University Studies on Space and Satellite Technology. Candidate and/vs. Graduate, a Case Study

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***Abstract*—Currently, there is a growing demand for most up-to-date academic courses that will fulfil the needs of modern society. Each candidate has to make choices and judgements carefully, in order to succeed on the market. This is particularly important when educating individuals with different backgrounds, especially on an inter-university course in the field of space sciences and technology. This paper describes a case study carried out on a group of candidates and graduates from different editions of Space and Satellite Technologies interdisciplinary master studies at Gdansk University of Technology as well as two maritime universities in Gdynia. The education process itself is realized in cooperation with business partners. The paper provides both qualitative and quantitative data, considering the whole group and particular individuals. In addition, some examples of individual achievements of outstanding students are presented.**

Keywords—Inter-University Studies on Space and Satellite Technology; candidates and graduates; university and business cooperation; career in space sector

I. Introduction

Three big universities in Tricity (the agglomeration of 3 cities: Gdańsk, Gdynia and Sopot in Northern Poland), namely, Gdańsk University of Technology (GUT), Gdynia Maritime University (GMU) and Polish Naval Academy in Gdynia (PNA), with co-operation with the Polish Space Agency in Gdańsk, started in 2017 the interdisciplinary, MSc degree studies on Space and Satellite Technologies (SST). Each of these universities offer for their candidates and conduct special education in case of certain specialty.

Faculty of Electronics, Telecommunications and Informatics GUT, recruits students for specialty: *Information and telecommunications technologies in space and satellite engineering*. Faculty of Mechanical Engineering GUT, recruits students for specialty: *Mechanical and mechatronic technologies in space engineering*. Faculty of Electronics Gdynia Maritime University, recruits students for specialty: *Marine satellite and space systems*. Faculty of Command and Naval Operations Polish Naval Academy in Gdynia, recruits students for specialty: *Space and satellite applications in security systems*.

This new initiative in the field of education in Polish Pomerania region is an answer to the development of the innovative industry sector of space exploration and utilization technologies. It is expressed by the increase of a number of companies and other entities related to space sector in Poland, also in Pomerania region. The new space sector entities are both the Polish branches of well recognized international corporations operating for a long time in space industry, and smaller local firms offering services in the areas including satellite telecommunications, satellite navigation, Earth observation and Geographic Information Systems.

II. Description of the University Studies

The detailed curriculum of the SST studies has been presented in [1]. The curriculum of the studies combines the contents of basic courses, like mathematics, physics or astronomy, with advanced topics of satellite technology utilization (satellite telecommunications, remote sensing and navigation), space missions, space mechanisms and constructions, as well as space applications in security systems. The graduates of SST studies also obtain skills on using as well as designing of specialized space equipment. The students are also provided with basics of legal regulations with respect to space activities. The wide spectrum of topics covered by the SST studies curriculum results in obtaining by students the background in numerous fields related to space.

Within the scope of educational activities predicted for of SST students during their studies, the directly take part in scientific research projects, under the supervision and in cooperation with the academic and research staff. As a result, they are prepared to independent formulating and solving scientific problems, performing the research, communicating with others and presenting the research results. He/she will be also able to solve several technical issues effectively, both in individual as well in team work. It include the design and implementation of the solutions specific to the area of a given specialty of the studies, also on the system level and including non-technical aspects in conditioning.

The studies of SST has obtained the financial support from the Polish National Centre for Research and Development in the form of the European Social Fund resources allocated for

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the implementation of the educational project "Adjusting the MSc studies Space and Satellite Technologies to the needs of the employment market". The activities undertaken to achieve the aims of the project rely on strict co-operation of the employers representing the space sector with the university. The representatives of firms operating in the space sector are taking part directly in preparing the contents of lessons for students, and also in delivering lectures and working with students during labs, seminars etc. Also, the team project and student dissertation projects are realized in co-operation with firms. As a result, students are expected to be better prepared to the requirements of the space sector employers.

III. Case Study Results

Three editions of the SST studies have been started so far, namely, 2017/2018, 2018/2019 and 2019/2020, the last one is currently in progress.

The case study has been carried out in April 2019 on a group of 20 people. It covered students from both the first and second year of the SST course. The survey consisted of closed and opened questions with single and multiple choices, in order to provide the best possible feedback and freedom of speech in case of each individual. The main aim of this case study was to determine their background, source of information, motivation, as well as expectations related with the SST course as well as space science as a novel and broad field of study. The extract from the results is presented below.

Fig. 1 describes the background of current SST students.

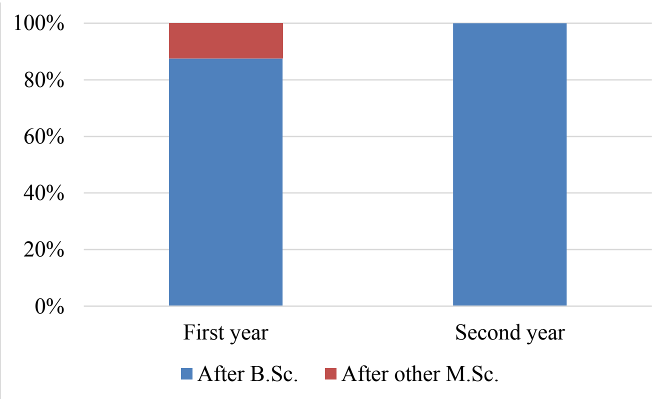

Fig. 1. Student background

As shown, in both cases the vast majority had chosen the SST course after B.Sc. studies. In case of the current first-year students, only approx. 10% had chosen SST as an additional M.Sc. specialty.

Their main sources of information, considering the third edition of SST course, are shown in Fig. 2. As shown, in case of approx. 50%, their main source of information was the GUT recruitment website. Internet advertisement campaigns, considering various adds as well as data distributed using social media, came in second. Other sources, including printed media, came in third place.

The main reasons and motivations for choosing this field of study, are shown in Fig. 3.

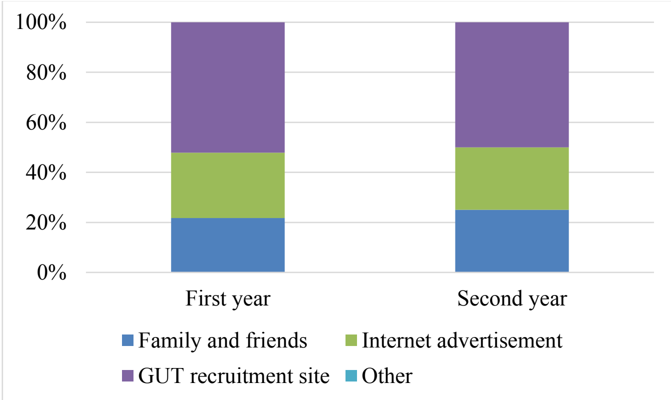

Fig. 2. Source of information concerning SST studies

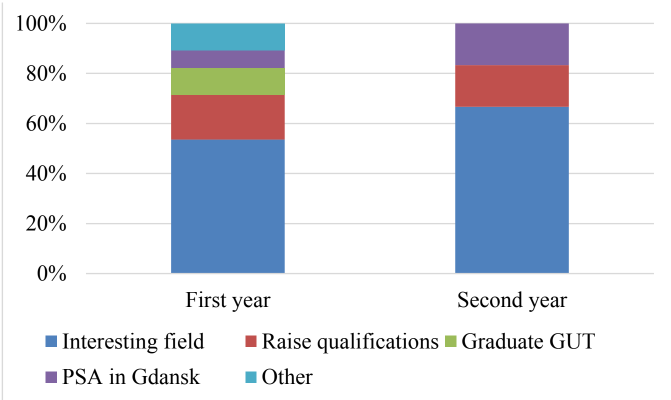

Fig. 3. Motivations for choosing SST studies

As shown, the vast majority concerned Space Science Technologies as an interesting and bold field of study. Some of them wanted to simply raise their qualifications or become a graduate of the GUT. Not surprisingly, a number of students pointed out the fact of founding the Polish Space Agency, headquartered in Gdansk.

The majority of SST students prefer laboratory and project classes over classical lectures (94% vs. 6% of the first year students and 75% vs. 25% of the second year students).

As pointed out, they desire to gain practical knowledge as well as typical engineering skills that can help them not only in private life, but mostly in their professional career. Currently, our SST course offers more laboratories and project classes, and most students would like to keep it this way. According to numerous answers, this course enables them to pursue their passion and learn unique knowledge and skills, that can help them find interesting jobs on the market. According to obtained results, as shown in Fig. 4, half of our students combines M.Sc. studies with professional work.

Whereas, most of them has part-time jobs, while some individuals favor self-employment. It should be noted, that some students had experience in IT and related fields from previous B.Sc. studies. Whereas others, that came from a different background, started their professional career after the first year of SST studies.

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Fig. 4. Combining studies with professional work.

Many individuals would like to pursue their passion, and continue studies as Ph.D. students. As shown in Fig. 5, their main motivation would be grants, closely linked with conference and publication activities.

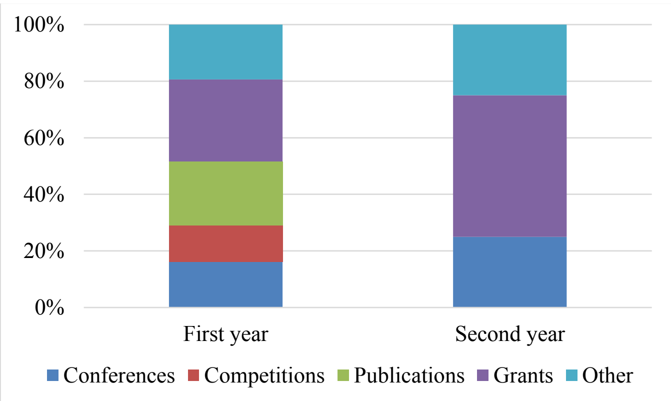

Fig. 5. Combining studies with professional work.

Naturally, the possibility of testing ones skills in academic and scientific competitions would be an important factor.

IV. Student Activities

In addition, it may be stressed that the SST students have got numerous achievements. The HEDGEHOG team [2] has qualified to REXUS/BEXUS programme, organized by German Space Agency (DLR) and Swedish Space Agency (SNSB), coordinated by ESA. The successful flight of the rocket with the experiment took place in March 2019. Currently, another group of students take part in the Spin Your Thesis! program. Apart from that, a number of students participated in space related conferences, workshops and other activities, including hands-on courses by ESA Academy: Concurrent Engineering Workshop, or Cubesat Workshop.

These students have founded a student organization SpaceCube. Its goals have been set to foster cooperation with academia and space sector companies as well as broadening the gap between course curriculum and future careers skills required by employers. Their main project is a nanosatellite type 1U Cubesat, aiming to test new type of solar cells developed at Gdańsk University of Technology. SpaceCube's activities include also popularization of STEM sciences among middle and high school pupils. Furthermore, their concept of "Space Navigation System", allowing for precise navigation on LEO and beyond was awarded 2nd prize at Poland's edition of Galileo Masters Competition 2017.

Engagement of three academia in space engineering resulted in some scientific results as well. A first PhD thesis in dynamics of spacecraft payload vibration is ongoing. Furthermore, a cooperation with Centre for Space Research of Polish Academy of Sciences has been developed to work on their space robot testing facility [3]. Additionally, members of faculty together with local space sector companies have proposed numerous research and development projects, some already funded by National Centre for Science and Development or European Commission. For instance, the subject of one project was the design of very light and durable lattice structure materials and the possibility of their use in the structure of satellites.

Another group of students was engaged in the project concerning floodplain inundation mapping using SAR data processing [4]. The study has been conducted in Biebrza floodplain, Poland, with the use of automatic thresholding method for processing Sentinel 1 data.

V. Conclusions

At the end, a preliminary sum-up may be made, although the SST studies were opened relatively short time ago, and the relatively small group of students has been covered by the mentioned study. Mainly, the SST students are well motivated to their educational, as well as research activities, usually indicating their real interest in space science and technology as the main reason for choosing this field for studying. Due to the interdisciplinary character of SST, the students, representing different fields from the point of view of their background, are open for learning new knowledge and skills as well as for participating in many activities like workshops, competitions etc. Also, the students are characterized by the high level of self-reliance and they are well prepared for combining the M.Sc. studies with parallel professional work.

As shown, the field of Space Sciences, in which our Space Science Technologies course is settled, is a novel and interesting research area. It attracts many young people, with different backgrounds, motivations and expectations. Most of all, it opens new frontiers and enables them to pursue their passion in one of the most rapidly developing field.

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Simplifying the design of smallsat space missions using innovative tools and platforms: beeKit and beeApp

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***Abstract*—There are three main barriers in the space sector that slow down the development of space applications, science and technology: high costs, consuming paperwork and complex technology. Open Cosmos tackles these barriers, putting satellite technology in the hands of more people than ever before. This is achieved with *bee*Kit, a payload hardware emulator platform, and *bee*App, a cloud-based mission and system simulator software. By using standardised interfaces and processes together with industry best practices, the entire development of a mission can be simplified massively reducing cost and time to orbit and opening space access to a broader and more diverse audience.**

The *bee*App and *bee*Kit bundle offers a seamless transition from payload concept to payload in space. *bee*Kit replicates the mechanical and electrical constraints of a satellite platform while still being modular enough to enable payload developers to change the configuration and physical dimensions. *bee*App enables full online mission with space simulation capabilities when the payload is assembled in *bee*Kit. The Mission and System Design (MSD) module allows users to run simulations and optimise different mission parameters based on the payload requirements. The Hardware-In-the-Loop (HIL) module interfaces with the payload through *bee*Kit, enabling smooth interaction and testing capabilities from day one. These constitute a set of groundbreaking tools that simplify the process of sending payloads to space.

Open Cosmos supports the education community by making those tools accessible for education projects. In 2018, a team of master students from Oxford University, without any space-related background, was able to conduct a biological experiment design for a 3U satellite platform. For the mission analysis and simulation phase, *bee*App was used to select the main mission parameters. A payload into a *bee*Kit was then designed to host cell culture flasks to control and monitor the cell death evolution. This approach facilitates cross-industrial research, at faster development rates, in a simple way and at much lower costs, enabling all kinds of organisations to conduct experiments in space.

Open Cosmos has recently established a program allowing universities from around the world to benefit from these innovative tools for free, supporting research activities and space-related education for students worldwide. This set of tools are now being used in 20+ different countries, in universities not only based in Europe, but globally, including space emerging countries. The goal is to continue enabling the development of new space technologies and applications and support space education programmes across the world.

Keywords— Space Mission Design, Space Education, Mission simulation, Mission Analysis, Payload, Smallsat

I. Introduction

The new space environment includes the emergent private space industry, specifically related to the community of space companies working to develop low-cost access to space technologies, as well as advocates of low-cost space technology and policy. New simple space mission development with decreasing launch costs for small satellites [2] allows an increased amount of satellites being deployed into LEO in short times and at reasonable costs. This trend opens the opportunity to create new capabilities and establish new business models around small satellite constellations. With the low latency telecommunications and high-speed data transmission capacities provided, it will become possible to provide satellite services over larger areas and increase the connectivity with these areas.

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This can enhance existing programs, such as remote medical support, remote education services or support to agricultural exploitation. Furthermore, the new panorama of satellite constellations will improve the establishment of communication networks in disaster areas or environment monitoring within others.

ESA has well acknowledged this new space context, promoting what is called the Space 4.0 era. It follows the Space 1.0 era (early days of astronomy), the Space 2.0 era (space race) and the Space 3.0 (ISS) era; so the main players now are the new increased number of diverse space actors around the world, including the emergence of private companies, the active participation of academia, industry and citizens, digitalisation and global interaction. This new era is unfolding through interaction between governments, the private sector, society and politics, with promising future missions ahead including new game-changing technologies.

Fig. 1: beeApp login portal page

II. Space Mission Design Tools

Open Cosmos approaches the new space era making satellite technologies easier and more accessible. This is achieved with *bee*Kit, a payload hardware emulator platform, and *bee*App, a cloud-based mission and system simulator platform.

A. beeApp: Space Mission Design software

Open Cosmos has developed *bee*App, a cloud-based software platform that enables full mission and system design with simulation capabilities to develop space missions. It allow users to:

- Perform mission analysis studies based on the payload characteristics that the user defines and the platform solution that Open Cosmos suggests.
- Interact with *bee*Kit in a Hardware-In-the-Loop (HIL) environment.

*bee*App includes different modules that can be used depending on mission requirements. The development page is divided into different tools such as the Mission and System Design (MSD) and the *bee*kit Hardware-In-the-Loop (HIL) tools. The Mission and System Design (MSD) module allows the user to perform mission analysis studies by running simulations based on the mission parameters. It hosts two main different sections, the inputs section and the outputs section only visible after running a specific simulation.

*bee*App is conceived to support payload developers during all stages of space mission development including high performance parameters typically from deep space long duration missions. The second module, called Hardware-In-the-Loop (HIL), allows each user to interact with their payload and test it.

B. beeKit: Satellite qualification platform

*bee*App enables full mission and systems development including simulation with hardware-in-the-loop when the payload is assembled into *bee*kit. Users can start testing and operating their payloads from day one and in a similar way as they will do it during the operations phase in space. It also simulates the behaviour of the platform configured by the user emulating its performance and constraints from the orbital parameters and subsystems selected. Once the payload is flight ready, it is integrated and tested into the chosen platform configuration and placed into the selected orbit via Open Cosmos approved launch providers, minimising time and cost. Once in orbit, the user can control the payload from *bee*App in the same way as during development phases while *bee*App takes care of limiting the operational boundaries. These boundaries are set by the system configuration, mission parameters and the ground segment providers partnering with Open Cosmos with the objective to minimise downtime and increase reliability.

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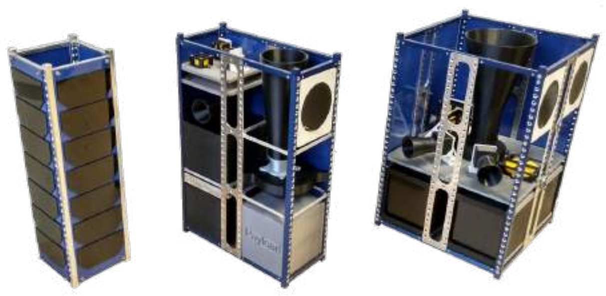

Fig, 2: 3U, 6U & 12U beeKit platform configuration

The HIL module allows the user to deploy software and perform functional tests of its payload once physically integrated into the *bee*Kit satellite qualification platform.

It contains the following features:

- File Management: the user can upload scripts/code to *bee*Kit and execute commands
- MSD Interaction: run scenarios on *bee*Kit simulated through MSD to validate payload performance
- Automatic Test Reports: users can export *bee*Kit sensors readings & subsystems performance.
- Operations interface: the user develops and tests the interface of the payload with *bee*Kit the same way it would be done at a later point once in orbit.

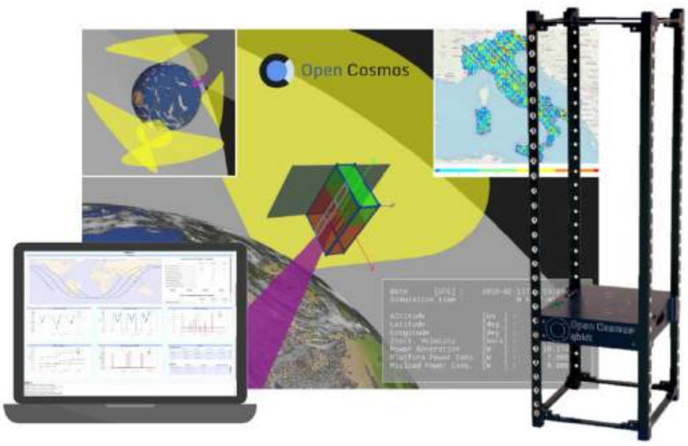

Fig.3: Simulation scenario with Hardware-in-the-loop module

III. Supporting space education

A. University Partnership Program

In line with Open Cosmos' ongoing efforts to democratise access to space and to enable using space as a tool, we are supporting and empowering the student community at University level with our tools to develop space technologies and applications.

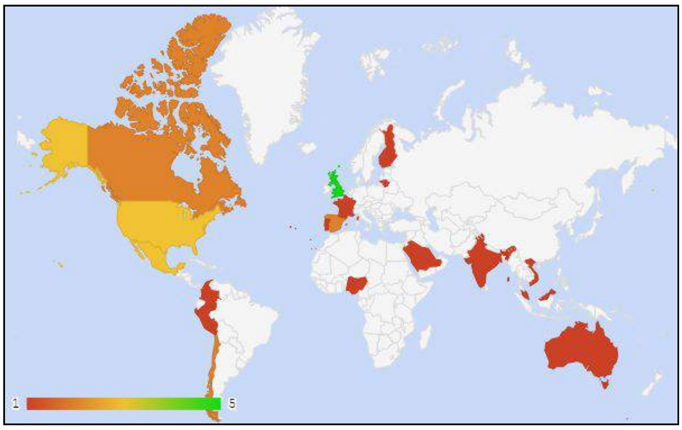

Fig.4: Open Cosmos' university partnerships worldwide

Open Cosmos has recently established a program allowing universities from around the world to benefit from these innovative tools for free, supporting research activities and space-related education for students across the world. This set of tools is now being used in 20+ different countries, in universities not only based in Europe, but globally, including space emerging countries, enabling the development of new technologies in space education programmes worldwide.

Open Cosmos supports the young community by making those tools accessible for education projects and emerging country activities by making use of a set of programs that allows the use of the Open Cosmos tools for free. The goal is to continue enabling the development of new space technologies and applications and support space education. In 2018, a team of master students from Oxford University, without any space-related background, was able to conduct a biological mission and experiment design and prototype for a 3U satellite platform. For the mission analysis and simulation phase, *bee*App was used to select the main mission parameters. A payload into a *bee*Kit was then designed to host cell culture flasks to control and detect any events and to monitor the cell death evolution. The outcomes were presented during the last International Astronautical Congress held in Bremen [1], proving that this new approach of developing smallsat space mission facilitates cross-industrial research, in

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a faster, simpler and cheaper way that enables any kind of organisation to conduct experiments in space.

The company is currently supervising and supporting student projects, aiming at developing new technologies to be integrated within Open Cosmos' satellite qualification platforms (*bee*Kits), in the UK with the University of Cranfield and France with Ecole Polytechnique, within others.

The different topics selected are enabling students to develop small satellite payloads and subsystems, being involved in a hands-on project that aims to design and build a functional demo unit of a payload (experiment, sensor, etc.) or a satellite subsystem, with its respective documentation: theoretical background, configuration instructions, list of components, assembly process, operations, etc.. allowing them to acquire knowledge in many different areas.

A team from Cranfield University is focusing on the development of a proof of concept equipment of a laser communication payload capable of sending basic information that could be suitable for inter-satellite communications. The payload should be able to send a receive information to and from other payload units, so the designed equipment can operate as a transmitter and receiver. Another team of students has been working on the development of equipment to monitor biological payloads in microgravity.

Open Cosmos has also initiated a project with Ecole Polytechnique based in Paris. The team of Master students from different backgrounds in physics, mathematics will work towards putting together an ADCS demo system based on reaction wheels, to improve attitude control. Once the demonstration payload is developed, it will be integrated into the satellite platform to conduct qualification tests. This will provide a great insight to the students on key small satellite technologies and processes to qualify a new system.

Universities developing payloads or technologies are also eligible to receive for free Open Cosmos' satellite platforms for testing and integration. A university in the United States is currently working on a prototype to develop a CubeSat hyperspectral, pushbroom imager; with potentially 4 more imaging systems in 2019 that would include an imager for detecting bioluminescence from space and a thermal imager. The university is using *bee*App software to simulate in-orbit operations and will be using later on *bee*Kit platform to integrate and start testing their imager.

In the vision of supporting space technologies and applications, Open Cosmos is providing credentials to access *bee*App software to any interested university. The *bee*Kit hardware emulator can be shipped to any university's premises currently developing a payload, sub-systems or technology and that is willing to use beeKit for integration and functional testing.

B. Open Cosmos outreach activities and education resources

a. Space Mission Design hands-on Workshop

The purpose of this workshop is to provide an introduction to space mission design and planning using Open Cosmos' *bee*App software platform. The curriculum of the workshop will cater to students, teachers and professionals, making use of the Mission and System Design (MSD) tool of *bee*App.

This workshop serves as an introduction to the key concepts of space mission design, to learn some of the theoretical concepts relevant to satellite missions, and have the ability to apply these concepts via several hands-on exercises, using online space mission design software.

b. Build, integrate and test your payload into a small satellite Workshop

Following the Space Mission Design workshop introducing the key steps of mission design and planning, students are given the opportunity to build, integrate and test payloads into real satellite qualification platforms using *bee*Kits.

The workshop is also focusing on the main aspects of payload design and requirements, followed by hands-on exercises allowing students to assemble either an Optical camera, IoT or biological demo payload to be integrated into OpenCosmos' *bee*Kit platforms, and run first functional tests using the *bee*App Hardware-in-the-loop module.

These two workshops have been taking place successfully in different universities around the world, receiving high appreciation and a very positive feedback.

Fig.5: Open Cosmos Workshop at the International Space University SSP19

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C. The Open Cosmos Academy

The Open Cosmos Academy is an initiative started by Open Cosmos with the objective of promoting the development of all kinds of space technologies and applications. It consists of the use of an online open source repositories (https://gitlab.com/OC_Academy) along with the corresponding documentation publicly available and open to contributions.

Thanks to the University Partnership Program, along with the hands-on Workshops, Open Cosmos is making efforts to support universities, helping to establish the basis for the next generation of space engineers and scientists that will benefit from using space as a tool. The development and results of new experiments, instruments and sensors can be documented and publicly shared through the Open Cosmos Academy, helping to distribute and expand the knowledge of space related projects across the international community.

IV. Space Emerging Countries

Removing the main barriers from the space sector allows more players and countries to enter in the space race. Euroconconsult has identified 20 New Countries that will Invest in Space Programs by 2025, with around 130 satellites forecast to be launched by emerging space countries in the next 10 years [3]. The small satellites technology offers a good opportunity for emerging countries to get involved in space-related activities and build capability and infrastructure.

Universities are playing an important and particular role in those countries, as space emerging programs are using education and academic institutions to support the development of space capability. Satellite projects are used as education tools to drive and push the development of first-generation satellite activities, whilst educating students and engineers from the home country [4].

The Space Mission Design tools developed by Open Cosmos give support to space emerging programs, allowing access to a set of tools and resources to education. Our university partnership program along with our workshops materials is enabling the support to human resources and training from regions worldwide. Our *bee*App software represents a first and simplified step toward understanding how to build and design a space mission, while our hardware emulator platform drives the development of their own capacity, from payload concept to payload in space.

The *bee*App and *bee*Kit bundle offers a simplified process to develop technologies and payload, helping the fulfillment of government priority needs for the country, while getting valuable data to solve countries issues such as land & water management, agriculture, disaster management, etc. Main objective of those countries is to demonstrate the government their capacity to build satellite & infrastructure, showing that it can be delivered to orbit with limited resources by individuals from the country [4]. Among 21 countries currently using *bee*App, around half of them are part of emerging space countries.

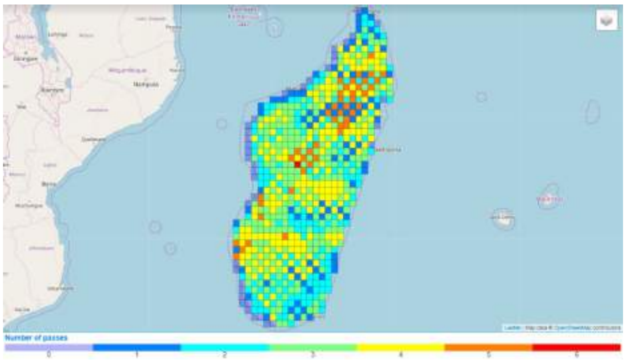

Fig. 6: Madagascar's heatmap and coverage using beeApp

V. Conclusion

Open Cosmos' set of tools included in *bee*Kit and *bee*App platforms together with the education resources developed, simplify the development of all kinds of space applications, experiments and technologies that can now be sent to space in a much faster way and at much lower costs. There have been lots of efforts done during the last 4 years in making complex technologies and processes much simpler so researchers coming from different industries can benefit from the space environment and from being in low Earth orbit. This simplified approach enables a broader and more diverse audience to access space qualified hardware and software tools to conduct experiments in space. This set of tools are already having a high positive impact in universities around the world, supporting research and educating the next generation of engineers and scientists that will contribute to improving the world we live in using space as a tool.

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Development of an Active Thermal Louver for CubeSats Controlled via SMA Actuator

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***Abstract*—In recent years, CubeSats proved to be valuable resources both for commercial and scientific purposes, leading to a significant technological development in terms of payloads and on-board instrumentation. The employment of more advanced technology usually implies a higher power consumption, and a consequently increased amount of waste heat. The typical, passive thermal control systems currently employed on small satellites, such as paints and coatings, may not be sufficient to guarantee a proper thermal stability, and therefore more elaborate and efficient systems are required. Based on the actuator IRESA (Intelligent Redundant Spacecraft Actuator), under development at the Chair of Astronautics of the Technical University of Munich, a new design for a compact, reliable, active thermal control system for CubeSats is proposed. IRESA is a shape-memory-alloy-based, low-power-consuming, high-force-per-unit-mass actuator embedded on a PCB, compatible with the lateral panel of a 1U CubeSat. IRESA produces a linear displacement of 3.5 mm exploiting the contraction of redundant SMA wires heated efficiently through the Joule effect; the displacement can be converted into rotation, allowing the actuator to operate a variety of subsystems. The presented design for the TCS consists of an external louver moved by IRESA, capable of modifying the emissivity of a small radiator or regulate the power emission from the inner part of the satellite to space. The design of the louver was obtained studying the louvered surfaces employed over the last fifty years in larger satellites and adapting the geometry to the features of the actuator, with the general design driver of a minimum complexity for the assembly. Therefore, a configuration with a single blade was chosen and implemented; like its larger counterparts, it reaches and maintains every angular position between the fully closed and fully open states, performing a 90 degrees rotation; the linear displacement of the SMA wires is converted into rotation by a simple lever principle. The proposed subsystem meets the CubeSat Design Specification in terms of geometry and compatibility with a CubeSat of at least 2U. The subsystem was developed as a master thesis project at the Chair of Astronautics of the Technical University of Munich starting from October, 2018. A prototype was successfully integrated in March, 2019, and good results were obtained during the first functional, vacuum chamber and vibration tests, during which the louver proved to work properly and continuously during the opening and closing procedures, and maintained its structural integrity.**

Keywords—TCS, thermal control system, louver, CubeSat, SMA, shape memory alloys, spacecraft, technology

I. Shape Memory Alloys and IRESA

A. *Physical properties of shape memory alloys*

Shape memory alloys (SMA) are a class of smart materials characterised by the ability to recover large induced shape deformations when undergoing a specific thermo-mechanical cycle. The most common variants of SMAs are nickel (Ni) and titanium (Ti) compounds with different percentages of the two metals, and the different alloys share the name of NiTinol [1].

The characteristic shape memory effect (SME) exhibited by shape memory alloys comes from the transformations occurring in the microscopic lattice when a change in the thermal and mechanical boundary conditions takes place. The SME displays as the material switches between three different stable phases: austenite, twinned martensite and de-twinned martensite [2].

In a stress (σ) - strain (ε) - temperature (T) space (Fig. 1), the thermo-mechanical cycle of the SME starts with the material in austenite form, which is the phase stable at higher temperature and characterised by an ordered, highly symmetrical lattice; following the curve, the subsequent formation of twinned martensite is achieved decreasing the temperature under no external load. Twinned martensite does not display macroscopical variations of shape if compared with austenite, due to the small rearrangements which occur in the microscopic lattice.

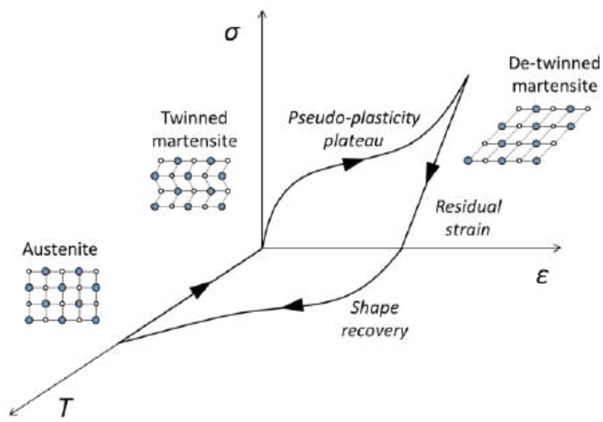

Fig. 1. The complete thermo-mechanical cycle of the shape memory effect, reworked from [2].

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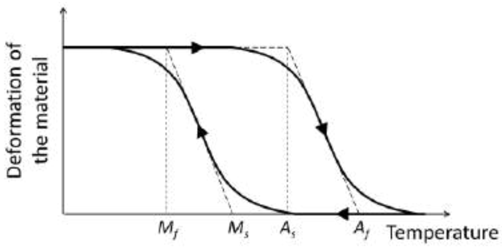

Fig. 2. The hysteresis curve associated with the SME with a highlight on the characteristic temperatures, reworked from [2].

Upon increasing the stress in the material, a first linear, elastic behavior is encountered, followed by a pseudo-plastic plateau in the $\varepsilon - \sigma$ plane. The plateau occurs at the de-twinning of the martensite. It has a nearly constant stress level; when the de-twinning is complete, the material responds elastically to a further increase in the stress level up to the yield point. At the end of the plateau, the formerly twinned martensite is de-twinned, and a macroscopical deformation is found in the material. Upon unloading, the material retains the induced strain, and only an increase in the temperature causes a recovery of the original austenite structure, eliminating every induced shape variation. The process of de-twinning can also be achieved progressively as the temperature decreases while an external load is applied constantly on the SMA, thus avoiding a clear mid-phase represented by twinned martensite and switching directly between austenite and de-twinned martensite.

In this case, when operating at a constant stress level the material exhibits a hysteretic behavior during heating and cooling (Fig. 2). Therefore four characteristic temperatures can be defined for the material: M_s (martensite start temperature), M_f (martensite finish temperature), A_s (austenite start temperature) and A_f (austenite finish temperature). For temperatures between the extremes of the transformation different fractions of each phase are found in the material: a specific shape is therefore associated to a determined temperature level or range, offering possibilities to exploit the response to temperature variations in order to control the behavior of the SMA and to make it suitable to be the active component in actuators and sensors [3, 4]. Strains up to 8% are possible for a sample of SMA, but lower values can be adopted as operative strain level in order to preserve the integrity of the material for a higher number of cycles, extending its possible service life.

B. *IRESA – Intelligent Redundant Spacecraft Actuator*

IRESA (Intelligent Redundant Spacecraft Actuator) is a compact, high force-per-unit-mass actuator operating with SMAs developed by the FGW Forschungsgemeinschaft Werkzeuge und Werkstoffe e. V. and the Chair of Astronautics (LRT) of the Technical University of Munich. The description of the actuator presented in this section is extracted and reworked from [5], in which the features of the hardware are presented in a more detailed way. IRESA makes use of NiTinol wires exhibiting the previously introduced SME: the wires are coupled with a return (bias) spring (Fig. 3), which provides the force necessary for the de-twinning process and the reset of the mechanism. The wires are in their de-twinned martensite state at room temperature, and they contract (passing to the austenite phase) when heated via the Joule effect. The actuator is embedded on a PCB and contained in an envelope of 80x30x8 mm, compatible with the side panel of a 1U CubeSat. The mechanism produces a linear displacement of 3.5 mm imposing a maximum strain of 3% to the wires. The mechanism is designed to reach an operative life of at least 5,000 actuations per wire.

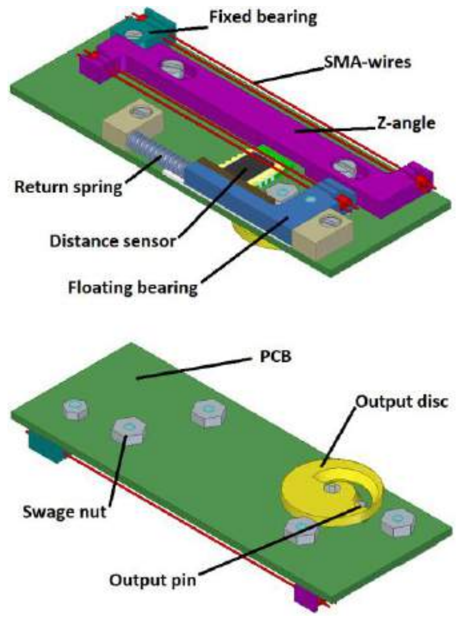

Fig. 3. The CAD simplified model of IRESA showing the main elements of the actuator; figure reported without modifications from original source [5].

The total length of the wires, corresponding to 131 mm, splits into two shorter wires (red colour in figure 3) which contract simultaneously, moving an intermediate Z-shaped element (violet) and producing the nominal output at the floating bearing (blue). The output pin attached to the floating bearing exports the motion, and connects to an optional output disk (yellow) mounted on the back of the board. The linear stroke of the pin converts to 180 degrees rotation of the disk. The board features redundant wires close to the primary elements, which form pairs, and work as back up units in case of failure or to perform a smooth switch without interruption of service when wear is detected in the main wires.

The output pin can attain and maintain every intermediate position between the two extremes, and a precise control can be performed during operations maintaining the temperature between the extremes of the transformation via a pulse width modulation. A position sensor determines the displacement of the floating bearing with a precision of 10 μm; a lower precision is achievable when the conversion into rotation takes place, due to tribological issues between the pin and the PEEK disk: an angular precision of ± 4° is possible with the current version of the board. The microcontroller MSP430 by Texas Instruments mounted on the board is characterized by low power consumption during operation, guaranteeing an extremely low idle power consumption for IRESA. Table I reports the main parameters of the actuator.

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TABLE I. IRESA DATASHEET; DATA RETRIEVED AND REPORTED FROM THE DATASHEET CONTAINED IN [5].

Parameter	Value	Unit
Mass	22	g
Idle power consumption	125	mW
Operative power consumption in vacuum	400	mW
Operative power consumption under laboratory conditions	1800	mW
Nominal output translation	3.5	mm
Nominal output rotation	180	deg
Rated output force	19	N
Reset time in vacuum at 20°C environment temperature	90	s
Reset time under laboratory conditions at 20°C environment temperature	35	s

II. THERMAL CONTROL SYSTEM AND LOUVERS

The use of an active thermal control system could prove beneficial for CubeSats both in case of cryogenically cooled equipment and in case a narrow temperature range is required for the internal environment of the satellite [6]. The greater stability offered by a more elaborate thermal control would allow for more power consuming and waste-heat generating technology to be mounted on CubeSats for operative or testing purposes.

Thermal louvers are thermal control systems which operate in combination with high emissivity surfaces, of which they are able to regulate the performance depending on the evolution of the internal temperature over time. They achieve this effect by means of movable external blades, which create a variable obtrusion to the power radiation with the external environment [7]. The main parameter used to characterize a louver and its effect on the radiator is its effective emissivity ε_{eff}, defined as:

$$\varepsilon_{eff} = \frac{q_{out}}{\sigma_{sb} A\, T^4} \qquad (1)$$

Effective emissivity correlates the amount of power q_{out} [W] emitted by a generic surface with the power emitted by an equivalent black surface with an equal area A [m^2] and at the same temperature T [K], and it is therefore an indicator of the efficiency of the heat transfer (σ_{sb} [W/m^{2}K^4] is the Stefan-Boltzmann constant). This parameter changes following the opening angle of the blades of the louver, with typical values of 0.08-0.1 for completely closed blades and 0.6-0.7 for a maximum heat dissipation configuration, i.e. blades open at 90 degrees [8].

The support structure and the aspect ratio of most louver systems have a strong impact on the effective emissivity, reducing the emission capabilities even in maximum heat rejection mode. The efficiency of the TCS is therefore partially impaired by the presence of the louver. Opposed to the classical geometry consisting in an array of blades, in the case of this subsystem a simpler configuration with a single moving panel was adopted and developed (Fig. 4) in order to a) maximize the radiation capability of the system reducing the number of obtruding elements and b) reduce the mechanical complexity in order to match the features of IRESA, which is designated as the only source of actuation of the system. The adopted geometry is able to guarantee a good power dissipation when the louver is open while still allowing for the maximum insulation in case the blade is completely closed.

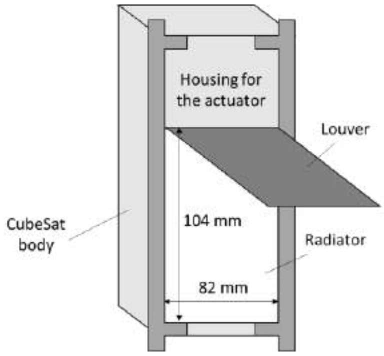

Fig. 4. A scheme of the preliminary design of the subsystem, representing the general structure of a 2U CubeSat.

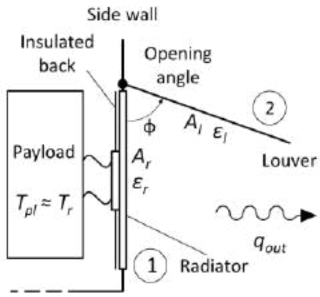

Fig. 5. The simplified thermal model accounting for the mutual interaction of the radiator and the louver.

The preliminary thermal analysis performed on the system is addressed to finding the potential operative range of the louver in terms of effective emissivity, as presented in (1) and in absence of external heat sources such as the solar power or the emission and albedo from the Earth surface. A simplified thermal model is implemented in MATLAB and two thermal nodes are considered: 1) the radiator and 2) the louver (Fig. 5); the two nodes are structurally decoupled and can only exchange heat through radiation, therefore parasitic conduction phenomena are neglected.

Future validations performed via experiments in a vacuum chamber could improve the model and verify the effect of the simplifications on its functioning. The performance of the system is assessed for a variation of the opening angle of the blade Φ (in the range 0-90 degrees) and for different values of the thermo-optical properties of the surfaces, respectively:

- ε_r, emissivity of the radiator in the infrared spectrum;
- ε_l, emissivity of the louver in the infrared spectrum;

The temperature of the radiator T_r is set at a sensible value of 15°C for every simulation. A hypothesis of isothermy

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between the radiator and the payload is made, synonym of a perfect thermal connection between the bodies, in order to reduce the complexity of the model. The size of the radiator and the louver in terms of areas A_r and A_l is the same as the one reported in figure 4, and it is derived from the standard size of a 2U CubeSat as regulated by the CubeSat Design Standard [9] and considering the size of IRESA as part of the side panel.

The presented plots (Fig. 6 and 7) are obtained for a variation of the emissivity of the radiator (ε_r) and the louver (ε_l). The preliminary results show a good capability of the system in decoupling the radiator from space in the fully closed condition (ε_{eff} below 0.1 for each value of ε_r) while allowing a power dissipation close to the one achieved by a non-protected radiator in the fully open condition; on the other hand, it is observed that in order to achieve a better insulation when the blade is closed the value of ε_l should be chosen as low as possible (ε_{eff} approximately or below 0.1 when ε_l is below 0.15), at least on the inner surface of the blade.

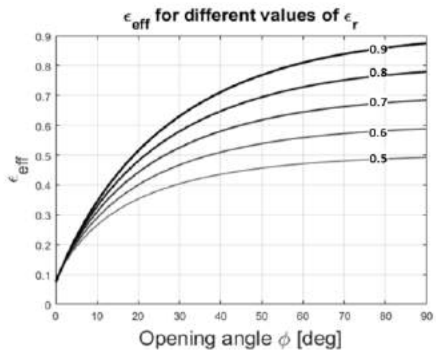

Fig. 6. The variation of ε_{eff} with the opening angle of the louver Φ for different emissivities ε_r.

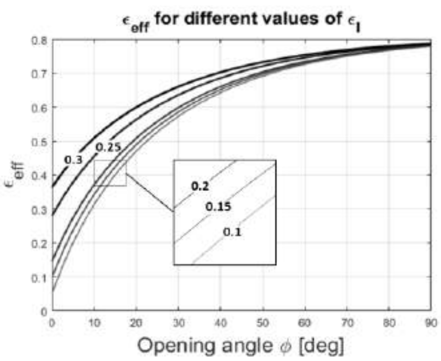

Fig. 7. The variation of ε_{eff} with the opening angle of the louver Φ for different emissivities ε_l.

III. Mechanical design

In order to guarantee the functioning of the system, a range of motion of 90 degrees must be produced by the mechanical connection between the louver and the actuator. A lever system is adopted to produce the rotation: a rigid connector is attached between the floating bearing of IRESA and the hinges of the louver, and it is designed in order to operate with a stroke d of 3 mm (Tab. II), accounting for some margin over the total stroke of the actuator. The lever is designed in order to avoid the occurrence of any mechanical singularity during the complete cycle, condition which may cause a locking of the blade or an increase in the internal forces of the system. The angular position of the louver is directly driven by the translation of the output pin (Fig. 8), but a torsional spring mounted on one of the hinges of the louver guarantees a reinforcement to the design, and generates an extra preload helpful in maintaining the blade at the desired angle (Fig. 9). The structural elements of the prototype are built with 6061-T6 aluminum, while polyether ether ketone (PEEK) is used for the connection elements between IRESA and the moving panel as well as for the hinges of the system.

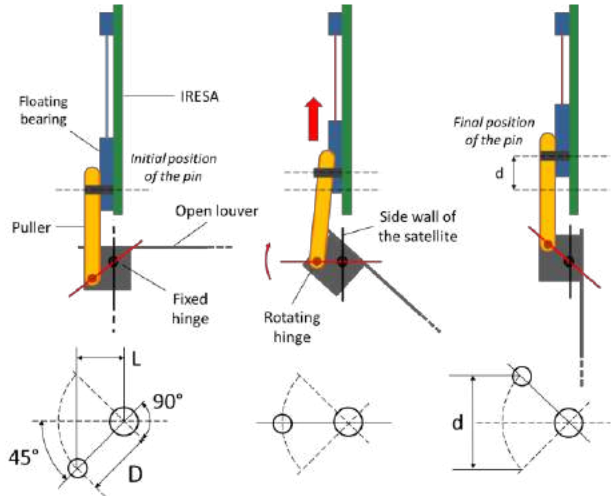

Fig. 8. A schematic working principle of the mechanics of the louver, showing a side view of the lever and the relative position of the hinges for three different configurations.

TABLE II. MAIN DIMENSIONS OF THE LEVER

Quantity	Value	Unit
D	2.12	mm
L	1.5	mm
d	3	mm

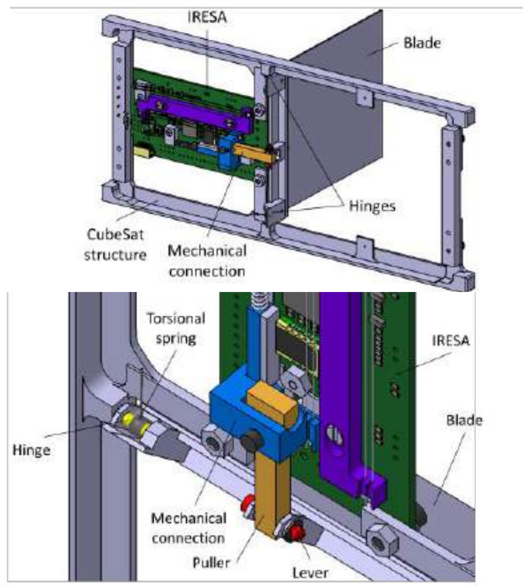

Fig. 9. The final design of the system, used to manifacture the first prototype.

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IV. PROTOTYPE INTEGRATION AND TESTING

The final design adopted for the mechanism was manifactured at the workshops of the Technical University of Munich, and successfully integrated in order to prove the absence of defects in the geometry of the system. Due to a fast production process, some of the tolerances on the structural elements were not matched properly, causing the louver to interfere with the fillets of the structure and to remain at an angle of approximately 80 degrees when fully open, instead of the nominal 90 degrees (Fig. 10). The first functional test consisted in verifying the correct closing and opening operations, and it was carried out by running a simple contraction-relaxation sequence of IRESA.

The results of the test (Fig. 11) prove that the lever operates correctly over the nominal range of motion, allowing for a smooth rotation of the panel. The plot shows that a final angle of approximately 5 degrees was reached before the opening procedure: this result is due to the non-complete contraction of IRESA under laboratory conditions, where the power and the time necessary to achieve a complete contraction are too elevated due to convective heat transfer between the hot wire and the surrounding air at room temperature. Tests run in a vacuum chamber are expected to remove this trend from the behaviour of the system and exhibit a complete closing of the panel.

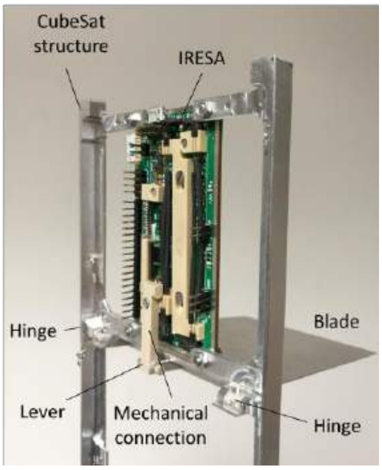

Fig. 10. The mechanical prototype of the system after integration.

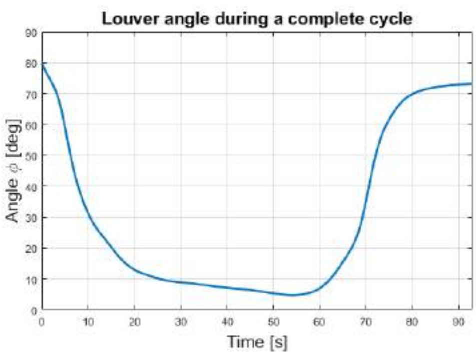

Fig. 11. The opening angle of the louver Φ over time during the first functional test under laboratory conditions.

V. CONCLUSIONS AND FUTURE WORK

In conclusion, the development of the subsystem proved the suitability of IRESA to operate as a spacecraft actuator, showing that a mechanical design focused on the specific features of the actuator is able to guarantee positive results immediately after the first integration process. Despite a good functioning of the first prototype, a further improvement is expected when minor issues are removed and additional tests are carried out in vacuum. A careful structural analysis combined with verifications through shaker tests are necessary in order to qualify the equipment for spaceflight; preliminary vibration tests were already carried out and successfully withstood by the prototype, but with slightly reduced loads with respect to what is specified by the most common regulations, due to limitations in the hardware at disposal.

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Three Main Activities of the Department of Education of the Polish Space Agency for 2019-2020.

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I. Introduction

Department of Education is one of the sixth departments in organizational structure of Polish Space Agency (POLSA) that was established by the Act of 26 September 2014. In general, the task of the agency is to support the Polish space entrepreneurs by combining the world of business and science. Additionally, the agency should support entrepreneurs in obtaining funds from the European Space Agency (ESA). An important aspect of the Agency's activity is to promote the development of satellite technology that can be used in everyday life, including communication, navigation, environmental monitoring and weather forecasting.

The Polish space sector has developed dynamically in recent years. This shows a need for dedicated education of human resources. On the other hand, further development of the sector depends on a ambitioned projects and programs implemented by the Polish government. This need raise with the level of public awareness associated with the impact of the space sector on the lives of every citizen. That is why the one of the important goals is also gaining public acceptation for the implementation of ambitious space-related projects in Poland.

To achieve both goals: building human resources and raising awareness related to the space sector, a number of education and training initiatives were defined as part of the proposal of National Space Program for 2019-2021. This initiatives covered all levels of education to reach the wide audience on the one hand, and focus on persons who could relate their future with the space sector on the other.

The mentioned tasks will be managed mainly by Department of Education of the Polish Space Agency. The department's employees are experts and specialists in the field of education covering different satellite and space technologies in particular space and earth observation, applications of global navigation systems and satellite telecommunications. POLSA education activities are also related to Polish Space Strategy established by the Act of Law in 2017. One of the goals of this act is also promoting the knowledge on the role of space technology for modern society and building human resources for development of space sector in Poland.

There are three programmes that among several activities of Department of Education as planned for 2019 and 2020 deserves for special attention namely: building the framework for school astronomical observatories, designing the tutorials for astronautics classes and establishing educational programme for increasing the awareness on air quality. The short description of them will be presented in the following sections.

II. School Astronomical Observatories

At the level of primary and secondary education, there is a tendency that many young people try to avoid the science. They consider it is difficult or boring. As part of higher education, however, the demand for mathematics, technical and natural science graduates is still growing. Traditional teaching methods and conventional assimilation of theoretical knowledge are not conducive to growing interest in interesting, though often difficult, physical and mathematical

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issues, and sometimes even discourage them. The alternative is the empirical learning, encountering difficult issues on the plane of direct sensations, visual observations and innovation. This approach has a chance to win more supporters among the younger generation, which is great important in the perspective of supplying the fields of study related to astronomy, satellite technologies and the space industry implemented at universities and technical colleges. Education in a dynamically developing field guarantees a perfect start into adult life, interesting work and implementation of ambitious goals and projects.

Astronomy is a science that combines many elements characteristic of exact, natural and humanistic sciences. Recent years have shown the incessantly faster progress of astronomical research, the growing interest of the media in informing about further achievements of astronautics and satellite techniques, successful space probe missions, or subsequent discoveries in remote corners of the Universe. These are issues that feed the imagination not only of young people, but generally of all people interested in the world, regardless of social status, occupation and age. Astronomy contributes to intellectual development, raising the level of awareness of the world around us and satisfying innate human curiosity. It has a fundamental, though not direct, influence on many areas of human life.

A properly conducted and used astronomical observatory can play a special role in the overall educational and pedagogical activity of the school. In terms of the long-term effects of the facility's functioning, they come to the fore, among others:

- Improving the quality of teaching.
- Finding talented students and supporting their development.
- Dissemination of knowledge about astronomy among children, adolescents and adults.
- Popularizing astronomical observations and research due to the use of innovative technologies.
- Increased interest in exact and natural sciences.
- Learning English in astronomical, technical and IT terminology.
- Preventing pathologies by organizing alternative forms of spending time.
- Popularizing the use of information and communication techniques to acquire and expand knowledge.
- Raising the winners of subject competitions and olympiads.
- Counteracting exclusion due to material conditions and place of residence.
- Increasing the attractiveness and competitiveness of the school in the context of using its pedagogical and educational potential.

III. FUTURE SPACE PROJECT

One of the most important activities for the astronomical observatory to become a permanent element of the school's current educational activity is to conduct lessons using its potential. These lessons, based on the current core curriculum, will undoubtedly stand out from the rest, and with their specificity will certainly attract a lot of interest. To meet these issues, POLSA in cooperation with the Nicolaus Copernicus University in Toruń is preparing a set of several dozen scenarios of full-scale astronomy classes developed by the didactic specialist of this subject. They can be used directly as part of the astronomical classes, as well as during geography, physics, nature, computer science and other lessons throughout the school year. They can be freely modified by the teacher and thus adapted to individual needs. The POLSA Department of Education expresses its willingness and readiness to create a publicly available script database, and thus complete new scenarios other than those listed there. POLSA is also extremely interested in suggestions for other than described possibilities of using the astronomical observatory scripts in education activities with talented youth.

IV. SCHOOL PROGRAMME AIMED FOR INCREASING AWARENESS ON AIR QUALITY

Inspired by this year Living Planet Symposium that was organized by ESA Centre for Earth Observation (ESRIN) in Milan and especially the presentation of its Air Quality Platform (https://lps19airquality.esa.int/), Polish Space Agency representatives in networking conversations with ESRIN representatives agreed to conduct the programme aimed for increasing awareness on air quality in Poland. The programme will be dedicated especially to young enthusiast, who – by using dedicated starter-kit style device – could register and analyse contents of several components of the air. The device could be easily mounted on an electronic testing board using miniature sensors that could be plugged to popular embedded open source hardware microcontrollers with dedicated firmware.

The first such devices was gifted to POLSA by ESRIN and measures several components of the air including temperature, humidity, particulate matters PM2.5 and PM10, nitrogen oxide NO_2, ammonia NH_3, carbon dioxide CO_2 and carbon monoxide CO. This device runs continuously at the Polish Space Agency headquarters in Gdańsk as the demo for visitors. At the same time the prototype of miniaturized version was developed in Education Department of POLSA that uses the same sensors as in ESA version. The miniaturization was achieved by using of NodeMCU compatible device with esp8266 microchip, which nowadays is very popular among enthusiast of Internet of Things (IoT). This device allows for establishing a WiFi connection to the Internet hot spots and at the same time allows for managing the measurements of all data sequences coming from sensors. As in the original ESA version the whole platform is equipped with four sensors measuring several air parameters like temperature and humidity, PM2.5 and PM10, CO_2, NO_2, NH_3 and CO. Fifth additional sensor namely GNSS receiver is

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dedicated not only to automatic extraction of device location but also for measuring of the track of a potential survey that may be organized by teachers for a group of youngsters and also for instructing on the role of all GNSS systems by observing dynamic sky view display of navigational satellites.

The crucial element of presented programme is also the software. ESRIN and POLSA agreed that variety possible hardware and software solutions must be compatible with server side platform established by ESA. In this way there is a future perspective of building the network of devices with in-situ data that could be used for verification of data coming from instruments located on satellite platforms.

The prototype version developed in POLSA will be also equipped with dedicated software that runs on mobile devices from which the miniaturized version could be powered. This aspect is especially important when young people on excursion will be hiking outside the regions of network availability.

The programme as being prepared by POLSA could be thought as a national version of pilot programme that - at the same time - is further developed by ESA in its education directorate. High level representative of ESRIN and POLSA agreed to do its best at this very early moment of air quality platform development to spread the knowledge on importance of air quality awareness in our future society.

V. Summary

It is necessary to establish the directions for future human resources training for the needs of the space sector. Due to their interdisciplinary nature, specialists in many fields find employment in creating new space technologies, including graduates of such fields as electronics, automation, computer science, mechanics, physics, navigation or even geography. Today, the strength of Polish space personnel is determined by solid education, primarily in the field of basic technical sciences. It is advisable that these specialists, in addition to knowledge in their fields, also acquire knowledge in the field of space applications. The most desirable form of such education seems to be graduate and postgraduate studies specializing in space and satellite engineering. That is why in 2016 Polish Space Agency headquatered in Gdańsk in cooperation with three Pomeranian universities namely Gdańsk University of Technology, Gdynia Marine University and Polish Naval Academy initiated the graduate studies on Space and Satellite Technology. Due to further needs coming from requirements from the sector Curriculum Board of this studies at the moment of writing decided to join University of Gdańsk as the forth pillar of this initiative.

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Space Career & Educational Opportunities through the ASTRI Programme

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***Abstract*—The following paper describes the purpose and benefits of the Advanced Student Team Research in space Industry (ASTRI) programme, as well as an example and programmatic outcome of a pilot project under the programme implemented by OHB SE.**

The ASTRI programme is a collaboration between European universities and private aerospace companies, and seeks to provide a structured transition between students' academic curriculum and their entry into the industry. There are three main ASTRI stakeholders, and their positive outcomes of participating in the programme are identified and listed. One of the main benefits is the establishment of a young and well-prepared talent pool of engineers.

OHB System, an established industry actor based in Germany, and the OHB SE subsidiary Blue Horizon, based in Luxembourg, participated in the first round of the ASTRI programme by proposing a project to develop a viable commercial micro moon lander concept.

For their ASTRI project, OHB implemented new approaches such as Concept Maturity Levels (CMLs) as a way to structure an 18-month long phase 0/A/B1 feasibility study. Each team member was given a role in the project. The roles typically included a technical aspect, where each member was responsible for designing a particular subsystem of the spacecraft, and a non-technical aspect, which could include topics such as business development, cost analysis, and project control.

The technical output of OHB's project include a developed lander concept seeking to accommodate a wide variety of customers and payload types by providing not only transportation to the lunar surface, but also necessary infrastructure needed by the payloads to successfully complete their missions. These infrastructure service concepts are geared towards eventually providing support for permanent human lunar settlement, a vision that will hopefully bring space exploration closer to the public and inspire the next generations.

Finally, the lessons learned by the team of students participating in OHB's ASTRI pilot project are presented. These lessons outline suggested improvements for future implementations of projects under the ASTRI programme, both at OHB and at other companies, in the hope that the opportunities that ASTRI introduces for students, universities, and companies are further enhanced.

Keywords*—*ASTRI; Moon; Lunar Lander; OHB System; Blue Horizon; KTH Royal Institute of Technology; University of Leicester; ISAE-Supaero; University of Stuttgart;

I. Introduction of the ASTRI Programme

The European space sector is expanding quickly, exposing an existing lack of skilled space engineers available to fill advertised vacancies. At the same time, the typical difficulties of entering the workforce with only an academic degree and little work experience remains a barrier to these same vacancies for those soon-to-be or recently graduated. The Advanced Student Team Research in space Industry (ASTRI) programme is an initiative intended to fill this shortage of engineers in Europe by closing the gap between students' academic and working career.

Spearheaded by Jean-Jacques Dordain, the former Director General of ESA, ASTRI is in essence a combination of a typical master's thesis project and an ESA Young Graduate Trainee (YGT) programme. Instead of being held at ESA however, ASTRI connects master's students from European universities with established private European aerospace industry actors. These private companies are invited to propose suitable projects they are interested in pursuing internally, after which students from the participating universities apply to said projects. The application process resembles a typical job vacancy application, and includes technical interviews. Students who are selected are grouped up to work together in a highly diverse team environment, intended to expose them to the typical international working culture of European aerospace companies [1].

The students are assigned individual work packages for the 18-month project, from which suitable thesis topics can be chosen. Fig. 1 shows the intended breakdown of an ASTRI project timeline. For the first six months, the participants work as typical students writing their master's thesis while located at their respective universities while being paid by the industrial partner. During the remaining twelve months, the team members relocate to continue the project at the companies as regular employees. This natural transition makes ASTRI a unique

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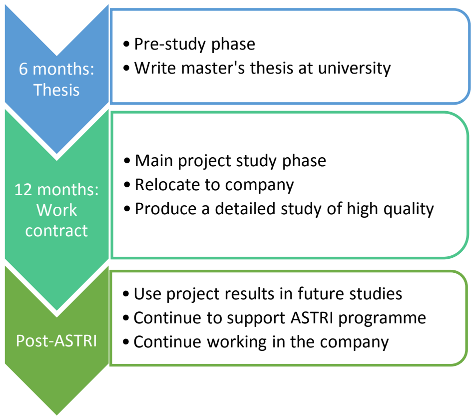

Fig. 1. Proposed ASTRI project timeline.

programme that facilitates the writing of high-quality theses with the help of a private company. The output of these theses are then immediately used to support a broader project with practical implications. This approach enables the students to both finish their master's degree while getting similar working experience that a YGT programme provides to entry-level engineers.

The goal of this paper is to raise interest in stakeholders, including students, universities, and companies, to participate in and take advantage of the great opportunities and benefits provided by the ASTRI programme.

II. ASTRI Stakeholder Participation Benefits

There are several benefits for each of the three individual participating stakeholders in the ASTRI programme, and these have been identified and are described below.

A. *Benefits for Students*

- Gathering of practical project experience in a real industrial environment and learning how the space industry works first-hand. This helps ease the career transition between academia and industry.
- Learning from industrial and institutional experts to apply the best approaches from both fields. Advice and guidance gathered while working on the project can help improve the skillset of the students.
- Working on innovative and highly interesting projects, which have an impact on the current environment of the space industry. This gives the students a relevant, modern look at the space industry to grant useful experience for future projects of a similar nature.
- Networking with industrial and academic experts as well as colleagues in an international environment. Knowing various work partners and organisations internationally leads to useful business connections for guiding and aiding career paths.
- Improving social skills by working in a highly multicultural environment. Working alongside colleagues from different nations and ethnicities allows for expanding perspectives and skillsets.

B. *Benefits for Universities*

- Expanding on student-led research developed in co-operation with private companies. Universities gets a chance to access and influence cutting-edge research influenced through their ASTRI students.
- Establishing stronger professional connections between the academic world and private industry to facilitate potential partnerships and relationships. The networking ASTRI enables can be used as a gateway for future research projects to be conducted, partially funded, and completed in cooperation with these companies.
- Improving university course content by creating a feedback dialogue between industry leaders and academics, allowing universities to tailor courses to industry standards. This improves employment prospects of graduates, which can further enhance the appeal of the university.
- Increasing recent graduate employment numbers, demonstrating high employment prospects for universities participating in the ASTRI programme. ASTRI has the potential to improve the career prospects of the alumni.

C. *Benefits for Companies*

- Obtaining technical outputs created as part of its ASTRI project implementation. Successful, viable elements of the resulting deliverables can be used directly for commercial gain or can be partially incorporated into other projects.
- Providing access to potential employees who have already been vetted to help fill internal vacancies. Furthermore, companies have the opportunity to guide, train, and develop young engineers into specific roles required by the company.
- Creating PR and company outreach to universities. The ASTRI programme has allowed university students to become more aware of these companies and this can help students, as potential future employees, learn about possible future employers.
- Creating parallel working opportunities on both the ASTRI project and other concurrent projects in need of staff. This helps the company immediately relieve its need for additional workers while giving further training to the ASTRI students.
- Testing team-working strategies across other remote sites and the use of concurrent engineering. The separation between team members allows for a unique environment for testing new tools, project management structures, communication tools and methods, and trial implementations of new workplace strategies.

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III. ASTRI-OHB Project Implementation

With the benefits of the ASTRI programme described, an example is given of how OHB System and Blue Horizon chose to implement its ASTRI pilot project.

A. Commercial Micro Moon Lander Theme

The theme of the project proposed by OHB is due to the recent attention that has been directed back to the Moon. Half a century ago, lunar exploration was politically driven by large government budgets, a necessity due to the enormous cost of resources involved. Due to the current NewSpace trend to faster develop better and cheaper access to space, the cost of participating in space exploration in general has been drastically reduced, enabling commercial endeavours and private actors to participate as well. Today, the private sector is being encouraged to participate in the renewed push for lunar exploration, thus allowing the free market to develop goods and services needed for a sustainable future lunar colony at a higher quality and lower cost than the public sector ever could. Both NASA and ESA, as well as some private organizations, have started projects and initiatives to encourage companies to help humanity return to the Moon, this time to stay for good. It is in this positive lunar exploration environment that OHB wants to get involved, and part of their approach is to assign the ASTRI-OHB team to study how OHB can join the commercial lunar exploration market.

The scope of the project proposed by OHB System and Blue Horizon is to develop a commercial micro moon lander service concept. This lander study would form the basis of a cargo delivery service intended to deliver customer payloads safely to the lunar surface. The commercial aspect of the concept was included in an attempt to expand OHB's potential revenue streams. The "micro" aspect limited the absolute size of the spacecraft, and one of the main difficulties of the study was to establish a financially viable, and sustainable, commercial service while maintaining this sizing constraint.

The current emerging commercial lunar exploration market is led by companies such as Astrobotic (USA), Israel Aerospace Industries (IAI) (Israel), and PTScientists (Germany). These potential competitors are all veterans of the Google Lunar XPRIZE competition and have close to a ten-year head start. The ASTRI-OHB team must find and develop its own niche to remain attractive to customers and remain viable to the company, in this competitive lunar lander environment.

Sustainability of the developed commercial service is crucial, as the target is not just the lunar surface. The Moon is viewed as a suitable staging ground and practice arena for eventual manned Mars missions and beyond. Supporting the necessary long-term human outposts, such as NASA's Lunar Orbital Gateway-Platform and the ESA's Moon Village, is a long-term goal of the CMML. As part of ensuring sustainability, OHB has also signed collaboration agreements on lunar landing missions with both IAI and Blue Origin (USA), and the ASTRI-OHB concept study needs to be folded into this collaborative environment to have the greatest impact.

The following mission statement has been constructed to communicate the main idea of the commercial service concept: "Due to the increasing interest in lunar applications, there is a growing need for a reliable transportation system that provides commercial access to the Moon. The ASTRI-OHB team will establish a regular and affordable payload delivery service to the lunar surface. The service is aimed at customers looking to perform rapid and iterative technology demonstrations, scientific experiments, and prospecting missions while promoting the development of a permanent lunar settlement". This mission statement tries to capture the team's core vision that has been held and refined throughout the project's lifetime.

B. ASTRI-OHB Project Structure & Roles

The study began with a kick-off meeting at the company location, where the students travelled to attend. This first meeting helped students to get to know each other and the team they will be working with [2].

The ASTRI-OHB team consists of nine members: eight students and one project manager. The student team is composed of six different European nationalities coming from four different European universities. Each student is allocated to an area of technical expertise with a Working Package (WP), as denoted by the various spacecraft Sub-Systems ('S/S'), as can be seen in Fig. 2. The students then selected an individual thesis topic in coordination with their thesis advisor and the project manager based on their S/S and their field of expertise that they would be working on. Each WP includes several technical and programmatic activities such as Mission Analysis, System and S/S design.

In addition to the distributed technical WPs, various non-technical roles were also split among the team. As the project is commercially oriented, a business developer and a cost analyst are required. One member is responsible for outreach and is in charge of every link between the team and external affairs. Finally, a project controller is in charge of establishing a project timeline to keep tracks of issues and tasks throughout the project. Those various non-technical roles help the team to develop the necessary skills that are important to be able to support other projects, and the company as a whole.

While the main objective was to learn how to accomplish a high-quality study, there were additional secondary objectives enticing for OHB as outcomes of the project. The participating students should take the chance to get to know the company from within, and to participate in different projects in parallel to the ASTRI-OHB study. This desire was included to both let the students broaden their learning opportunities and to allow OHB to temporarily fill vacancies where there was an immediate lack of skilled employees.

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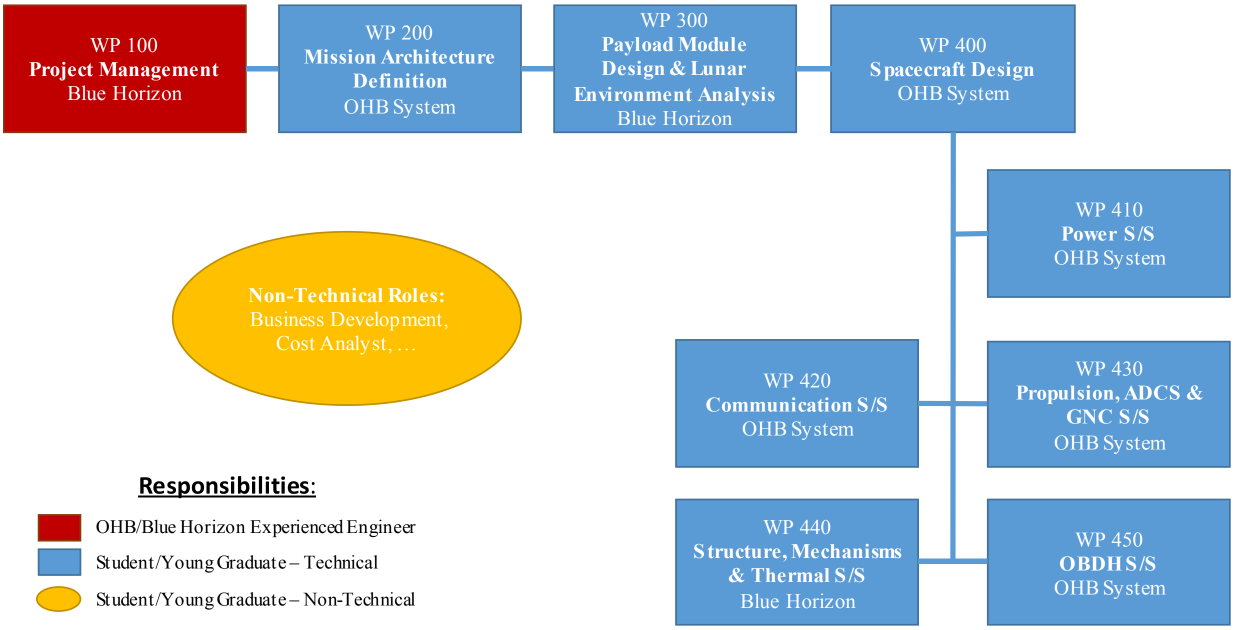

Fig. 2. ASTRI-OHB project structure and WP allocation.

Another objective assigned to the team was to propose the usage of new communication and exchange tools, as well as new ways to implement concurrent engineering. This objective was necessary due to the geographic differences of the team members during the initial 6-month thesis project phase and the high IT Security standards of the company. Several solutions were adopted, such as the Remote Desktop application for remote document and tool access, and the concurrent engineering software IDM-CIC. The implementation of these tools was tested in various remote workshops and team meetings, showing their capability of satisfactorily improving work efficiency. Furthermore, additional solutions were identified as highly interesting for the application in the company but could not be implemented within the frame of the project.

OHB chose to implement a specific project structure, known as Concept Maturity Levels (CMLs), to organize the project. The CML approach contains nine milestones to reach and fulfil, corresponding to phases 0/A/B1, and were developed by NASA's Jet Propulsion Laboratory in order to have a solid pre-development plan up to a project's Critical Design Review (CDR) [3]. Each of the levels have numerous tasks to complete in order to go from one level to the next. At the start of each new level, the team agreed upon which tasks would be tackled for the next milestone review and these tasks were kept track of by the project controller.

IV. ASTRI-OHB Lessons Learned

With the first batch of ASTRI projects wrapping up, the lessons learned by the ASTRI-OHB team are compiled to help future programme participants have a better ASTRI experience and to improve the efficacy of the programme. Comments about the project have been separated into identifying project elements that went well, those that should be improved upon, and those that went wrong.

A. *What Went Well*

- The dedicated time given to learn about all facets of a project, including technical, management, financial, etc. This allows for familiarisation with the project, enabling students to assist in more areas than just their assigned work packages.
- The transition from university to company. By assisting the students with this transition, company processes, private industry logic, and desired company skills can be instilled in the recent graduates.
- The different project opportunities available to the students. As company employees, the students are capable of working on other company projects in parallel to ASTRI, allowing them to gain additional working experience.

B. *What Needed Improvement*

- A technical internal advisor should be assigned to each team member already before the kick-off of the project, to provide proper guidance. This issue was identified as a critical point as numerous times the lack of experience by the students lead to complications, delays, mistakes, and avoidable challenges if someone had been available to point out the issue earlier. The company should also spread awareness internally so colleagues are aware, and thus able, to assist the team where expertise is required.
- The project could be built to better accommodate university involvement. Aside from technical assistance during the first 6 months of the project, university involvement was smaller than anticipated. Ideally,

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universities would work with the companies more closely to attend reviews as reviewers. One solution to this is ensuring that Non-Disclosure Agreements (NDAs) are signed before the project begins. Awareness of the programme within the universities was small, and this too could be improved by potentially linking the project to research within the university. This could also be used to help set up projects with universities and the companies, which in turn could further involve the students.

- External reviewers should provide feedback within the first few months to ensure that their comments can be implemented effectively. Input from external reviewers was received late in this project but this feedback would have been good to have earlier on.

- Organize lectures and workshops for team members to help them develop basic skills and knowledge needed for the specific project. The students' academic background may not have provided all technical (or non-technical) skills needed to complete a project at an industry level. Through this process, the company can identify workshops needed for all employees as well.

- To prevent that high IT-Security standards prevent the students from testing new tools, a sandbox environment could be implemented in which the students can test new tools without violating the IT-Security.

- Communicate in advance the tools already used and the tools the different departments are interested in as an input for the selection of tools used by the students to maximize the outcome for the company.

C. *What Went Wrong*

- Some problems arose due to the CML tasks being geared towards scientific missions, and it was determined that the CML structure should be modified to fit commercial mission development. Consequently, the reviews at each level were missing deliverables needed when designing a commercial concept while including unnecessary scientific tasks.

- Access to digital tools like CAD software was highly or completely restricted because of limited number of licenses or because of licensing issues between OHB System and Blue Horizon, because they are located in different countries. The consequence was that for some tasks the mandatory tools were not available.

In order to improve the overall ASTRI programme concept, an "ASTRI Alumni" group should be established and gather at regular annual or bi-annual meetings, both to collect feedback from multiple ASTRI project teams and to network between the teams.

V. Conclusion

The ASTRI programme is intended to enrich the European aerospace industry with a new approach to introduce newly graduated students into the work force. The programme realizes this by establishing a team of students who work together within their master's theses on the same project in an industrial project frame. The participation of academic and industrial advisors gives the participating team members a chance to learn from both, and provides at the same time unique networking opportunities in an international working environment.

OHB implemented their ASTRI project as a phase 0/A/B1 study on a commercial micro moon lander. The theme of the project highly motivated the team and expanded their scientific, technical, and programmatic experience in a currently hot topic in the space industry. The results and outcomes of the project study will flow into the other lunar activities at OHB, and will help develop the various cooperation agreements already established between OHB and other international companies involved in lunar exploration.

The ASTRI-OHB pilot project revealed certain issues of the first implementation of the programme. Some prior preparation for an ASTRI project is required, such as contacting sufficient external reviewers, signing NDAs with academic advisors in advance, the accommodation of supporting industrial advisors, and setting up the working environment needed to try new digital tools for communication and engineering.

As a pilot project, a lot of useful information on how to implement an ASTRI project was gathered by OHB. These lessons learned can be used by other companies and OHB itself to improve the next iteration of the ASTRI programme.

Acknowledgments

Credit is given to OHB System and Blue Horizon for proposing the project, providing the work environment, and assistance throughout the project. Credit is also given to Jean-Jacques Dordain and the organisers of the ASTRI programme for providing the opportunity to work on the ASTRI-OHB project. Finally, special mention must be made to Nicolas Faber, COO of Blue Horizon and project manager for the ASTRI-OHB project.

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Supporting a University Satellite Engineering Team via Inclusivity and Initiative

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Abstract— **Any university-based satellite engineering team that hopes to design, build, launch and operate even the most modest of satellite missions is likely to encounter enormous resourcing difficulties. Unless you are fortunate enough to receive support from, e.g. a well-funded research group, it is normally extremely difficult to raise the amount of funding needed. In a research-led university, such a 'practical' project rarely has the 'currency' of research publication output even if it carries potentially very high profile exposure for the department/university.**

The University of Warwick Satellite (WUSAT) Engineering Programme has found ways to overcome this ongoing problem ever since its inception in 2006. This paper describes how resourceful and inventive the Directors and students have had to be in order to facilitate the achievements that the team has made over the past thirteen years.

What is described in this paper is not just a mechanistic approach in 'how to get things done on a tight budget', it is also a description of how to develop an attitude and a culture that makes a wide range of individuals and organisations feel that they are part of the wider 'WUSAT Team'. It is an illustration of 'thinking on your feet' when an opportunity arises for you to offer something to someone else rather than just thinking about what you want from them. The reward for the team will come in the payback that almost inevitably comes from organisations/individuals whose trust and respect you have earned.

This paper describes many examples of such relationship-forging events. These include examples involving,

- **Partner companies,**
- **Warwick University staff/resources,**
- **The inclusivity and diversity of the wider WUSAT team,**
- **Other external agencies.**

Of course, this doesn't exclude the need for direct financial support altogether, but the culture and approach described in this paper is at the heart of why the WUSAT Programme has been successful, and why it has become widely recognised within the Higher Education Space Engineering community.

Keywords—satellite engineering, WUSAT, project resourcing, funding, resourceful, inventive, attitude, culture, team-mentality, inclusivity, diversity.

I. INTRODUCTION

The University of Warwick Satellite Engineering Programme [1] is a series of Space-related activities based around the core activity of its Satellite Engineering Team. All activities work under the acronym, 'WUSAT'. The WUSAT project team is a multi-disciplinary team of 4th Year MEng students. Their contribution to the current WUSAT project in any given year comprises 25% of their 4th Year programme of study, and the School of Engineering provides a nominal amount of funding per student. However, the scale of WUSAT projects undertaken, and the high profile of WUSAT achievement, far outstrips the modest funding provided. Hence, measures to meet the shortfall are continually sought by the WUSAT Project Directors. At its inception in 2006, the WUSAT project team almost immediately became the primary electrical power supply subsystem team for a European Space Agency (ESA) Moon orbiting satellite (ESMO) [2].

Since 2012, WUSAT has developed its own CubeSats, each designed and built from first principles to meet a specific objective. This included a two-year project terminating in a successful sounding rocket launch (2013-15) via the ESA REXUS programme [3], and during 2015-to-Present, four years development of a 3U CubeSat designed for Low Earth Orbit via an ESA 'Fly Your Satellite via the ISS' programme [4]. The main objective of this latter project (WUSAT-3) is to provide a proof of concept for a RF signal direction finding technology that could enable the development of smaller, lighter wildlife tracking tags. This would enable a range of wildlife species, previously incapable of being monitored, to be tracked from LEO. It is clear that the scale of these projects requires a range of activities to be undertaken, and each of these can carry a substantial cost.

II. POTENTIAL COSTS

For each WUSAT project these can include,

- Materials and components for prototyping, testing and eventual build
- Manufacturing costs
- Software licences and potential training for specific software packages

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- Travel and accommodation to attend ESA design review events
- The use of test facilities, including in-house facilities in some cases.
- Costs involved with developing and supporting company partnership links.
- The cost of producing promotional and outreach materials, and attending related events. This is considered a major priority for WUSAT as we promote our students, the School of Engineering, the University of Warwick, our partner companies, and ESA who themselves are providing launch opportunities via their outreach funding. This can take the form of team polo shirts (reproduced annually for each team) containing the logos of all of our partners, banners & posters, travel/accommodation to give talks and attend conferences, etc.
- Potential costs incurred through registering radio communication frequencies for mission use.
- Insurance costs.

If admission to an ESA launch programme is obtained, an amount of ESA sponsorship will be offered in addition to the launch costs. However, this is often limited to a small number of team members attending an ESA programme event. Any other team members attending these events will require flight/accommodation costs, etc, to be sourced from the project budget.

In addition, due to the activities of WUSAT projects, the Directors of WUSAT are regularly invited to take part in a wider range of Space-related activities. These form the wider WUSAT Programme, and include;

- The formation of a 'virtual' research group of academics who have research specialisms potentially applicable to Space [5].
- Membership of a Midlands Innovation Space Group – associated with the development of the new 'Space Park – Leicester' and looking at ways of developing a strong Midlands Space cluster of active universities and companies.
- A group formed through the Satellite Catapult to investigate the possible use of satellite technology to counter the activities of illegal wildlife poaching.
- Acting as the catalyst in a general review at the University of Warwick, designed to identify and bring together all potential resources that could combine to make Warwick a leading university in the area of Space Engineering and Technology.

We consider these activities to be an important part of WUSAT development. They increase our knowledge, extend our network of contacts and help to increase the profile of WUSAT, our partners, and the University of Warwick in general. However, they also have a cost in terms of time, effort and travel on the part of the two WUSAT Directors. This cost can be either sourced from the (already inadequate) WUSAT budget, or self-funded as a 'personal interest' activity.

Of course, the act of pursuing additional funding, in terms of determining what suitable funding is available and making an application for it, can itself be a costly exercise. Both WUSAT Directors are already highly committed/? in terms of the time given to both the WUSAT project and the wider WUSAT Programme, so finding the resource to pursue additional funding can itself be problematic. The remainder of this paper highlights the approach taken by the WUSAT Directors, and gives specific examples of measures employed in order to gain benefits for WUSAT that have allowed us to achieve a great deal on a minimum budget.

III. Creating a Team Culture for Everyone

The main starting point when creating a working cultural environment that will encourage others to 'buy in' to your project, and eventually support you with it, is to provide INCLUSIVITY for everyone. In a university-based multidisciplinary engineering team, it is vital that a strong team ethic is in place in order for everyone to feel that they are fully playing their part whatever their particular skill or contribution.

However, it is just as important that other members of staff (technicians, academics, office staff, and university management) all feel that they are part of the extended 'team'. You will need things from all of these people over the lifetime of any significant Space project, so it is important to keep them in touch with progress, show your appreciation of what they do, and look for any opportunities whereby you can do something for them.

Similarly, when hoping to form partnerships with companies or other organisations, keep mentally putting yourself in their place. Rather than just thinking what you want from them, think what it is that they want from such a relationship with you. Companies rarely have access to a budget where they can just allocate funds to an educational project, but they will often have a wide range of other things they can offer you, and in many cases these can be worth a great deal of money if you had to fund them yourself (see later specific examples). Once you are able to talk with them, listen carefully to what they say. If you are inventive with your thoughts, you may spot opportunities where you can do something for them. Keep them informed of what you are doing and take every opportunity to include their name and contribution in your own publicity output.

When you nurture such relationships, it can sometimes be 'further down the road' before an opportunity suddenly arises whereby a relatively casual relationship with a company becomes very 'centre stage'. A need suddenly arises that has great interest and relevance to you and the company, and you are then pleased that you kept in touch and kept them informed!

An additional, and important, aspect of our 'team' approach at WUSAT has been to form strong links with the Warwick Aerospace Society. This has allowed us to run additional projects, e.g. CanSat, with teams formed by students from across a range of Warwick departments. This can have many benefits for WUSAT-3 and for our partners.

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IV. Initiative – Typical Examples

This section is effectively the 'methodology' of this paper. It describes a range of initiatives that have not only increased the level of inclusivity in what we do, but has often brought considerable, direct benefits to our work. When operating on a minimal budget, these actions and the response they bring are often the difference between success and failure!
In most cases, except where it is unavoidable, we have kept the names of companies and individuals anonymous.

A. WUSAT Team Day

Towards the end of each academic year, we always hold a 'WUSAT Team Day'. We invite all of our participating partners to attend. The WUSAT Directors give a presentation on developments with the wider WUSAT programme, and the student team present their technical work and activities completed over the year. We then have a meal in a Warwick Conferences restaurant. There is ample time for networking, discussing new ideas and future plans. This is a most enjoyable day, and partner representatives really appreciate meeting the team and each other!

- Points to note – we do not refer to the companies as 'sponsors' as that implies a one-way relationship. We refer to them as 'partners', and the whole day as a 'Team Day' because we are all 'in the team', and that is the culture we wish to promote.
- Benefits –
  - Company partners feel fully included as part of the team and want to contribute in any way they can because it is 'their' project and not just something they are supporting.
  - Partners feel appreciated for what they do rather than taken for granted. Hence, they are often likely to offer more if they can.

B. University Appointments

A previous partner company representative wanted to remain research active to pursue information relative to the project. A letter written to the appropriate department at the University of Warwick to request that this person is appointed a Fellow of the University was successful. This gave them a Warwick University log-on, and access to research papers through the university library.

- Benefits –
  - It gave the company employee access to a resource they could not easily acquire, and enabled them to research information relative to the project.
  - It demonstrated that company/university relationships do not have to be 'one-way' but that WUSAT can offer benefits to the company too.

C. Assisting University Staff

Technicians in the University of Warwick engineering workshops are very skilled and do an excellent job. However, they are often under a lot of pressure to complete work for research and other student projects. Following the launch of WUSAT-2 in 2015, we learned that a submission was being made on their behalf for the National Papin HE Technician awards. We wrote a substantial reference in support of this submission, based on the excellent contribution they had made to the success of WUSAT-2. As a result, they were invited to attend the prestigious Awards Evening where they were awarded one of the top national prizes.

- Benefits –
  - The engineering technicians have never forgotten that the WUSAT Team went 'out of its way' to support them. When there is pressure to prioritise work, WUSAT requests now always receive favourable consideration.
  - The technicians now feel that they are part of the team, as indeed they are. We often invite them to presentations, etc, for that reason.

D. Company Internships

Helping to provide a good intern student to a company with a specific short-term need, can be a powerful way of assisting the company and potentially gaining favour with them if they can help you. For example - On meeting the CEO and representatives of a particular high-tech company, initial discussions seemed not much more than an exchange of information on our respective areas of work and the fact that 'somewhere down the line' there may be something we could do together. However, when the CEO happened to mention that they were mainly physicists who now needed to gain more engineering knowledge – particularly in the area of thermal modelling – we saw an immediate opportunity to provide them with a good mechanical engineering intern who could do just that. The company were delighted with this possibility, and when we managed to get the student appointed through the Warwick Summer Internship scheme, the student's six-week internship was also fully funded.

- Benefits –
  - We earned the trust of the company because we made a suggestion and followed up on it for their benefit.
  - We now have a close relationship with the company.
  - They have generously offered us an expensive, flight-tested piece of equipment that we can use as part of the payload for WUSAT-3, plus a second that we can use as an engineering model for prototyping, etc. This would have cost us thousands of pounds if we had to procure it

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ourselves. We hope that both parties will now benefit from a very positive relationship.

Linking partner companies to any university internship scheme can be a very productive way of providing a benefit to the company and enhancing your relationship with them.

- Benefits –
  - One beneficial outcome that companies often desire when supporting a university project is to recruit good quality graduates. Students completing an internship with a company is often the best way of the company seeing them at work and potentially pre-recruiting them prior to graduation.
  - If a student is a potential recruit to your university team, arranging for them to do an internship with a partner company can be an ideal way of inculcating them into your project and your specific technical links to the company.
  - We have had a number of occasions where a student on an internship with a non-partner company, then progresses into the WUSAT team. Due to their contacts and close ties with the company, they have then subsequently brokered a WUSAT partnership arrangement with them. This has been enormously beneficial for WUSAT in the past. Some of our major company partnerships have been obtained through that route, where otherwise 'cold calling' can be far less productive.

E. Contributing to Company Promotional Activities

Partner companies are very keen to promote their brand and to show their products/services being used in high-profile Space projects. Making the time and effort to help facilitate this with company partners can bring many rewards. WUSAT examples include;

1) *Writing articles for a company newsletter, journal, or website.*
2) *Contributing to a company promotional video*
3) *Attending company outreach displays at, e.g. Science Fairs*
4) *Producing a case study for a company, often for display on their website.*
5) *Giving a presentation at a company/partner symposium*

- Benefits –
  - *(1)* – Articles in company promotional outlets are also a 'free' promotion of your project and gives added kudos with your name linked to the company and their brand [6].
  - *(2)* – WUSAT recently offered to support RS in a promotional video they were making. The result was also a brilliant promotional video for WUSAT itself [7]. In addition, during filming for the video, we happened to mention WUSAT's role in the forthcoming 2019 British Science Festival based at Warwick. RS responded by offering the use of their Titan demonstration lorry packed with interactive modern engineering technology [8]. So the outcome of our willingness to support RS was two significant contributions to WUSAT that we could not possibly have afforded.
  - *(3)* – Partner organisations will often attend outreach events in their own right, but will be keen to show their links to top-class university projects by having the project team and artefacts from the project on display alongside the organisation's main display. Again, this provides 'free' publicity for your own project, and enhances your standing with the partner company.
  - *(4)* – WUSAT once collaborated in a major case study [9] with a software company, displayed on their website. The benefit was free licences for use of the design software by team members.
  - *(5)* – Partner organisations will often hold workshops/symposiums of their own [10], and you will enhance your standing with them, and will be much more likely to receive benefit from them, if you are willing to support these and make presentations, etc, when you can.

- Point to note –

  The activities described above can be demanding and time-consuming when you already have a busy project to run. However, it is worth remembering that

  a. If you receive funding from your university to run a high profile project, there is some expectation that you will promote it and engage in outreach activity, e.g. Open Days.
  b. The partner organisations that are supporting you and lending their name to your project reasonably expect to see this promoted where possible.
  c. If your project operates through, e.g. an ESA programme, then the funding and support received from them is part of their outreach funding. Hence, there is reasonable expectation that you will have some sort of outreach programme yourself.

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Hence, you will have some level of duty to take part in these activities in any case, so you may as well do it in collaboration with your partners and obtain the benefits that go with it.

V. CONCLUSIONS

Finding the time to produce additional promotional/outreach material, or pursue some initiative, for partner organisations can be difficult when you are running a busy project. It can be the easiest thing to ignore or put off for another time. However, the examples given in this paper show that the benefits derived from pursuing such activities when you can, can be incalculable.

If you are working on a limited budget and need additional resources to help you complete your project successfully, then adopting and developing this cultural way of working from the outset can reap enormous benefits. Of course, you must be careful not to say 'yes' to everything, but overall it is an extremely pleasant and rewarding way to expand the scope of your project and form many useful, close, working relationships.

Points to note –

- Student members of your team can of course, contribute to such activities. However, our experience is that even the most mature of students do not always have the confidence or experience to 'pitch' a particular approach to a potential partner in a way that makes it attractive to them. They are also not always aware of the range of benefits that may be available through university resources, etc. Hence, it is normally best for project supervisors/directors to lead on these matters. In any case, you normally want student team members to be working on technical matters!
- The limitation to this approach is, of course, flexibility. You can only obtain a desired product or service from an organisation if firstly, you are able to form a relationship with them and secondly, they are willing/able to make that provision because of your relationship with them. Clearly, you cannot just make a partner of every company that you need to acquire something from on the expectation that they will just give it to you. Most partnerships have to be nurtured on the sole expectation that they will offer you things when/if they can. Financial resources are still very much required.
- Any shortfall in funding, not forthcoming from sponsorship or benefits in kind, will be dependant upon the University underwriting the project. In order to achieve this commitment, the University needs to perceive that there is adequate benefit. The approaches identified above are fundamental to achieving the maximum benefit not only for WUSAT but also for the University. Our focus on missions that have a real-world application has allowed us to enhance our outreach activities, with WUSAT-3's mission of wildlife monitoring providing an excellent opportunity to engage non-traditional audiences (e.g. gardening groups, bee-keepers, ecologists etc) in the excitement of an engineering project.

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BiSKY Team, an aerospace-focused interdisciplinary student project

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***Abstract*— BiSKY Team is an aerospace-focused student group from the University of the Basque Country (UPV/EHU, Bilbao, Spain) where it is a recognized teaching project. It was born in 2018 and its main activities deal with the development of the technologies involved in the design, manufacture and launch of suborbital rockets. This team is currently the only Spanish university team involved in the research and construction of hybrid engine rockets. The primary objective of the team is to enable young science and engineering students to acquire expertise in the aerospace field, and several transversal skills as well, by designing and constructing space vehicles. Further purposes include promoting science and engineering among high school students and children and to also reduce the existing disparity between male and female involvement in science, technology, engineering and mathematics (STEM). Besides, the project will make interesting contributions to space science by providing researchers with the means to test their experiments in zero gravity and high-altitude vacuum.**

BiSKY Team is divided into several specialized groups: i) Aerodynamics and Recovery, ii) Propulsion, iii) Avionics, iv) Flight Control and Simulation, v) Business and Management and vi) Structure. This interdisciplinary project makes the collaboration among all groups crucial. In this regard, the team stands for respectful cooperation between all its students. BiSKY Team is an example of a multidisciplinary student project that implements innovative technologies allowing not only its members, but also members of other student research groups and training centres, to enter the competitive sector of aerospace engineering and space science research. Even if this is a university student-developed and managed project, vocational training schools' involvement is also considered. Close contacts with research and technological institutions as well as industrial companies are pursued looking for technical advice and financial support.

Within the operations of the team, several phases are being undertaken in order to acquire the expertise necessary to design, manufacture and launch a hybrid engine rocket that reaches an altitude of 100 kilometres, also acknowledged as the Karman Line. The phases include the development of two engine test stands, a flight simulator and the complete avionics for the rockets and test stands. The expertise gained through the implementation of the mentioned technology is being applied in the hybrid engine rockets of the so-called Cosmox family, whose primary mission is to reach space and allow the research experiments to be carried out. The design of the Cosmox and future families of rockets is iterative, giving continuity to the project by allowing next generations students to get involved.

Keywords—aerospace; hybrid; rocket; student; team; inclusive; women in science; technology

I. INTRODUCTION AND STATE OF THE ART

50 years ago, mankind first stood foot on the moon during NASA's world-famous Apollo Program. Neil Armstrong´s historic words as he stepped down from Lunar Module onto the lunar surface where sent down to earth, to Spain´s *Maspalomas* telecommunications station, thus making this country part of an extraordinary endeavour. Today, almost no one in Spain is aware of this fact, and the space topic as a whole is regarded as a dull subject, even as a delusive one, by the general public.

This disregard for space is in part due to the absence of professionals with hands on experience in the field at academia. Despite having participated on the development of the Ariane family of launchers, built and operated its own satellites, and contributed to many international scientific and robotic missions, space technology is an uncommon topic in Spanish universities [1].

Students from the University of the Basque Country founded an engineering student group focused on the development of its own suborbital space launcher. Despite de activity being technology based, the end goal of the project is to encourage space enthusiasm amongst both existing university students and future generations, stimulating the pursue of STEM careers in benefit of all our society.

Half a century ago, at the time when the Saturn V was being developed, it seemed impossible for a group of students to undertake what only governments could barely accomplish, with seemingly unlimited resources when compared to those of the current student project. However, advances in rocket propulsion technology have resulted on the emergence of hybrid chemical propulsion, where a mixture of solid propellant and liquid oxidizer are used to power the rocket engine. This technology allows for the development of high thrust rocket

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engines with a much greater security margin than their liquid and solid counterparts, as the propellants are inherently safer to store, transport and operate with. Moreover, these engines are simpler to design and fabricate with conventional manufacturing resources, in such a manner that even students can accomplish it in collaboration with specialized companies.

There has been no other entity in Spain thus far that has developed real hardware for hybrid rocket engines, making BiSKY Team a national first on the application of hybrid propulsion for rockets. Traditionally, only the National Institute for Aerospace Technologies has directly worked with rocket propulsion, in the form of solid fuel engines for military applications, but nothing close to the real engines being developed at BiSKY Team [2].

In the last decade, the number of aerospace student led projects across Europe has become remarkable, many focusing on satellite technology, but most being centred on the development of rockets. The current common goal for all projects is to develop the technology to reach the frontier between Earth´s atmosphere and outer space, also known as the Karman line. Being able to do so not only provides international pride and recognition, but the possibility of offering local scientists and researchers an easy, cheap and reasonably reliable access to suborbital space flight of small payloads.

This paper introduces BiSKY Team's progress both in the technological and educational field since it was born in September 2018, emphasising the facts that made this university project thrive. The rest of the work is structured as follows. In Section II, the project's main objectives and scope are described as the project's raison d'être. Technical planning is detailed in Section III and IV. In Section V, the benefits for students involved in the project are presented, followed by Section IV, in which transversal competences developed are more detailed. Finally, Section V concludes this paper and focuses on BiSKY Team's future work, also referred as "team" from now on.

II. Objectives and Scope

BiSKY Team pursues two different types of objectives: ones dealing with competences and skills acquisition and others related to the development of suborbital launchers. Both are strongly connected as the second ones are the main tool to fulfil the first objectives.

A. General objectives

Important efforts have been undertaken all over Europe since the last decade to foster young vocations for the STEM studies. One of the most attractive aspects of science and technology is the development of impressive products (equipment, vehicles, software,…) proving the extraordinary connection of science and technology with our present technological lives and the incoming future. As a consequence, BiSKY Team tries to be an additional contribution in this promotion work around our area of influence, even at elementary schools.

The early involvement of a high percentage of female engineering students in the team is a promising response, due to the low involvement of women in STEM careers at the university in which BiSKY Team is based. Since its creation, BiSKY Team has been trying to fill the existing gap in male and female involvement in the aerospace sector by creating a non-hostile working environment and doing outreach.

As a secondary objective, BiSKY Team tries to foster the pubic appreciation for the technologies related to space science and engineering, especially in the Basque Country and in Spain.

Spain has recently seen the creation of some NewSpace start-ups such as PLD Space or Zero2Infinity, but a lack of industrial tradition, and as a consequence, infrastructure, has sometimes acted as a roadblock for the rapid development of said companies. To compensate the lack of tradition, BiSKY Team is involved in projects where universities and companies collaborate to create an adequate environment for a further development of technology and the corresponding industries. Some examples are listed below:

- Cooperation with research groups by enabling micro-g experimentation, making it easier, faster and cheaper for the local research community to carry out their experiments. Basque university groups have already shown interest for this kind of cooperation.
- Apprenticeship and collaboration with companies related to the aerospace sector. The support and feedback of highly experienced personnel collaborating with the team and its members gives the opportunity for participants to acquire business experience as well as technical advice.
- Apprenticeship and collaboration with other educational institutes as professional training, with the aim of allowing university students to better understand manufacturing processes, as well as enhance the motivation of students of this kind of schools.

B. Specific objectives

The specific objectives are the ones dealing with the design, manufacture and launch of suborbital vehicles. These objectives include many different sub-objectives: from getting the required financial support to obtaining a working space at university, from specific software development to detailed thermomechanical and aerodynamic simulations, from parts fabrication (with a lot of collaboration form vocational schools) to their final assembly, from an adequate collaboration following rules and standards to a quasi-professional management of the project.

In the next section the scope of this paper will focus on the description of the ongoing activities related to these specific objectives.

III. Recent and Ongoing Activities

In order to design a rocket capable of reaching space, the corresponding project must consist of several phases divided

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into two different work areas that enable the application and the verification of the technologies involved.

First, the development of commercial launchers based on solid fuel engines with the aim of developing and testing the avionics and flight simulator completely developed by BiSKY Team. The phases are named after the rocket developed: Alpha, Bravo and Charlie. Alpha is the first rocket launched by BiSKY Team, in September 2018, which fulfils the following objectives: i) Dissemination of the project and recognition by different associations and companies, thus gaining credibility to be able to obtain the necessary financing, ii) Creation and testing of a first flight simulator, iii) Development of own technology required for the launch, flight and data collection. Bravo was able to measure altitude, pressure, gravity, angular velocity and obtain GPS data. As a result, the avionics could make in-flight decisions like deploying the parachute, save the data in an SD and send them via a telemetry link. Finally, Charlie will be a demonstrator of the technologies implemented in Cosmox, being able to entirely test the recovery system and electronics.

Second, the design and manufacturing of hybrid technology engines. Therefore, two test stand engines are being developed, denominated M1 and M2. M1 is a proof of concept that is not meant to fly but to obtain data and acquire know-how. As this is the first engine designed by the Team, its components are simplified. Gaseous oxidiser is used, leaving the vaporisation apprenticeship for the M2 engine. Heavy, high-temperature materials constitute the chambers and the nozzle so as to ensure the data acquisition for which this engine is constructed. With the obtained information, the team's own simulator will be tested and used to design the second hybrid engine, M2. M2 is a more representative engine which can easily be integrated into Cosmox. It is a powerful engine based on lighter materials, liquid oxidiser, optimised nozzle, a more advanced feeding system with a swirl injector and an in-house designed tank. After M2 testing, Cosmox will be built and launched, propelled by a self-designed engine.

IV. Cosmox rocket

The final goal of the first three years of BiSKY Team activity must end with a self-designed hybrid engine rocket and including innovative solutions in its avionics, its recovery procedure and possible applications. In Figure 1 a simplified representation of the technical planning for the final design of this rocket is shown.

M1 and M2 testing stands will be crucial to optimise the different systems to be integrated in the Cosmox engine: the N_2O pressurized low-weight storage and the corresponding filling station, the oxidant injection system and the combustion chamber, the solid fuel composition and the high-temperature nozzle. From a detailed analysis of all the data gathered using previous solid engine rockets, the avionics, the flight simulator, the recovery system and the possible pay-loads incorporation will also be optimised.

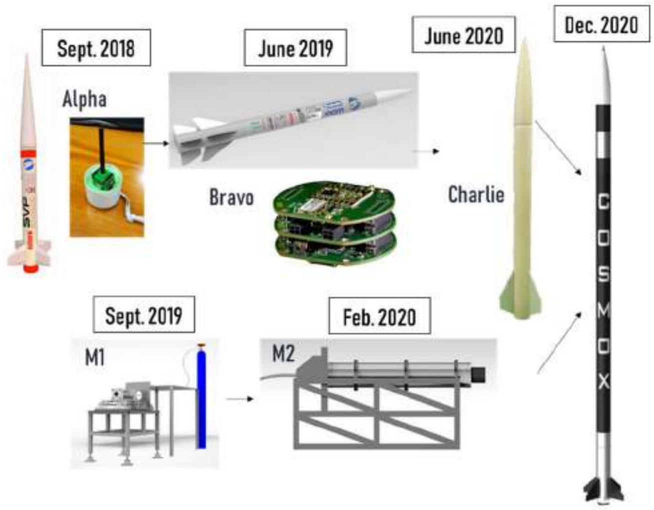

Fig. 1. Schematic of BiSKY Team's technical planning to Cosmox rocket.

After the first Cosmox rocket is launched, named Cosmox I, one Cosmox rocket will be designed and launched every year, each one improving the technology and design of the previous rocket's components. The project's final goal is to design a Cosmox rocket that will reach the Karman line, commonly referred as the boundary between the atmosphere and space.

V. Benefits

The aforementioned interdisciplinarity of the project is a key aspect of the educational benefits that the students involved in BiSKY Team gain. It allows the sharing of knowledge among the students of different university degrees in the framework of the design of a rocket. This framework also provides the members of the team with a practical focus and application of their knowledge, be it their own expertise or the knowledge gained from interactions with other members who are knowledgeable in other areas. This practical approach to the learning experience complements perfectly the sometimes too theoretical education received at university.

Apart from the shared knowledge and the practical applications, there is also an inherent benefit to being involved in a project like BiSKY Team in the form of the self-education that is necessary. Although most of the concepts required for the design and operation of a space vehicle are too specific to be developed in full detail in class, the basis upon which to build the necessary skills is fully covered. This presents the students with the perfect opportunity (or obligation) to acquire the knowledge by themselves and then prove their understanding with the application of their newly gained know-how on a rocket, a skillset that is really valuable if the student is to enter the professional market.

The different backgrounds of the members of BiSKY Team also present the participants with an excellent opportunity of networking outside their specific fields of study, building strong relationships with future professionals of the wide range of fields involved in the project. Apart from the networking within the team, BiSKY Team favours the expansion of the network of

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Fig. 2. Transversal competences acquired by BiSKY Team members.

its members by being a project actively involved in events related to aerospace activities such as conferences, symposiums and rocketry competitions. This also allows its participants to broaden their perspective of the space sector and NewSpace actors that will, in the future, be some of the entities that employ them.

VI. Transversal competences

With this project, team members have the opportunity to develop not only technical skills, but also transversal competences or "soft skills" as the ones shown in Figure 2. The team has the chance to experience a full business situation, gaining confidence in fields such as teamwork and leadership and becoming familiar with both self and group organisation.

The support received from companies varies from financial aid - essential in this kind of projects, where the investment in technology is significant - to technical assistance. This is a very much needed and appreciated knowledge which fills the lack of experience in fields that are rather unknown or new to the student.

The above-mentioned interaction with enterprises enables the students to have a direct relationship with possible employers, which is beneficial for both parties. On the one hand, the employer has the possibility to meet well prepared and hardworking students with an interest in the company. On the other hand, members have the opportunity of not only writing their bachelor's or master's thesis at one of this enterprises, but also getting to know possible future workplaces which is an advantage when trying to get a professional position such as an internship. In addition, members master how to hold presentations, attend to meetings, write emails and many more. This, in turn, results in an even bigger educational benefit for the student in question, as they will not only develop their skill set at BiSKY Team, but they will also be able to grasp how the professional working environment is.

At the same time, participants learn how to work under pressure and how to multitask, for they have to continue with their university studies while they are active members of the project. This shows a full commitment and hard work from the members, as it is a voluntary project. All that is achieved with both high motivation and effort.

VII. Conclusions

BiSKY Team is a university level rocketry team born in September 2018 with the aim of designing and manufacturing its own hybrid rockets. This is a novel project in Spain, where there has been no other entity developing hybrid rocket engines so far. A students-group of the University of the Basque Country gave birth to this project in order to enhance aerospace technology and science apprenticeship within engineering and science colleagues in a practical way. But not only involved students take benefits of the project, the team also gives prominence to their stakeholders such as sponsor enterprises, professional training institutes and young schoolgirls and schoolboys. The team aims to capture the interest of young school students and women, promoting the female participation in this sector. Consequently, BiSKY Team is continuously participating in aerospace related events related to aerospace activities: conferences, symposiums, rocketry competitions, etc.

As for the technical procedure, the team's planning is divided into two work areas in order to construct an entirely self-designed hybrid rocket. The first one focuses on the development of complete own avionics and testing of the team's flight simulator with the rockets Alpha, Bravo and Charlie. The second one is the design of hybrid rocket engines, two engine test stands are being developed so as to ensure the required know-how to develop the team's first hybrid rocket, Cosmox.

Finally, future work will focus on the development of BiSKY Team's first hybrid rocket as well as on the improvement of its technology year by year. In that way, the team will be able to support research groups that need launchers for different experiments. At the same time, gaining a reputation may attract the attention of young students that might want to get involved in the aerospace sector. This may help strengthen the aerospace science and technology network.

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Insight into the benefits of ESA Education activities: an overview of the next European space-related workforce

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***Abstract*— Growing efforts are currently being addressed by ESA to support the next-generation of space professionals and researchers. ESA's Education Office is successfully creating a network of individuals sharing and promoting dedication to space technology on the basis of the values of trust and cooperation. In this framework, students and early-career researchers can rely on experienced tutors and professionals to improve their area of expertise effectively. This paper provides a detailed insight of the utterly positive return on the careers of who had first-hand experience of ESA's Academy activities, both through training courses and hands-on projects (as REXUS/BEXUS program). The authors have contributed in many different and unexpected ways to the advancement of their fields of study and/or work. Accordingly, the outcome of this paper is a vivid and varied patchwork of people from various professional backgrounds reflecting on their experience and thus depicting the actual situation of the young European generation in the space sector. What links the authors of this paper together is their participation in the five-day didactic training course "Concurrent Engineering Workshop" held in May 2018 at ESA ESEC facility. During the workshop, the students worked as a team to develop a mission architecture for a satellite impacting the Moon surface, surviving and deploying a scientific rover: LIAR mission (Lunar Impactor And Rover). The concurrent design study offered a realistic environment to work within, amidst different scientific backgrounds and expertise, thus leading to a challenging and rewarding learning opportunity. This paper will also discuss the Concurrent Engineering development cycle, by giving an overview of main carried out activities to present the most important lessons learned. During their involvement in ESA's educational programs, the participants had been given a precious perspective on the tools and strategies behind ESA's space missions. One year later, the participants are still in contact and committed to fruitful collaboration aimed, among other things, at creating a space start-up. The example highlights that educational support constantly proves to be the key to a successful and prolific future of space sector by encouraging and technically challenging passionate students.**

Keywords—Educational Activities; Early Career; ESA Academy; Network of Professionals

I. INTRODUCTION

The development of highly skilled individuals provides an invaluable asset to foster the growth and success of the European space sector. In this regard, ESA Academy learning courses provide a treasured opportunity to obtain an insight into how different disciplines depend heavily on each other during satellite development and how a space system works. Furthermore, the ESA Education Office is offering hands-on activities (as REXUS/BEXUS, Fly Your Satellite, etc.) aimed at improving the practical skills of students and preparing them to their prospective job in the space field.

In particular, the authors of this paper took part to the learning course ESA Academy "Concurrent Engineering Workshop May 2018" (or "CEW May 2018") hosted at the Training and Learning Centre of ESA-ESEC, Belgium. In this occasion, 20 students from different ESA member and associate states were invited to participate in an educational mission

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feasibility study. The attendees have been divided in small groups and assigned the design of different spacecraft subsystems. The course was orchestrated by ESA experienced professionals who introduced them to the Concurrent Engineering methodology [1], moderated their interactions and offered advices and solutions to emerging problems. The students were challenged to define a preliminary architecture for a prospective mission named Lunar Impactor and Rover (LIAR).

This paper will firstly provide an overview of the ESA Academy's Concurrent Engineering Workshop of May 2018, referring to the main challenges the students faced during the course. Then, it will present the most valuable lessons learned by the team both generally and individually on professional and personal levels. To conclude, some final thoughts and prospective collaboration opportunities are reported.

II. ESA ACADEMY CEW: LIAR MISSION

LIAR mission concept involved a satellite to reach and impact the Moon at high-speed, survive the landing and deploy a rover to search for water. Each team of students had specific objectives to reach at the end of the five-day workshop: the most challenging ones are briefly reported in Table 1.

TABLE 1. Challenging mission objectives

Team	Subsystem main objectives
Configuration	Define the location of the different subsystems and equipment on the spacecraft
Structures	Design a structure withstanding the impact on the Moon while being still able to deploy a rover
Propulsion	Determine the propulsive strategy, entailing burns and possible break at the Moon with a retro-stage
Mission	Define the orbit of the satellite, the ground station contact time and eclipse duration
AOCS	Select equipment based on pointing requirements and possible spin up/down methods for the solid stage
Power	Define the total power budget and determine how long the system/rover can survive a Lunar night
Comms	Design the communications subsystem and identify the OBDH hardware based on data rates and ground station contact
Thermal	Design the thermal control system for both spacecraft and rover and assist configuration
Optics	Define optic sensor for navigation and pictures of lunar surface to be fit on the rover

The participants were encouraged to propose their design ideas and left a huge amount of freedom in their solutions (even in the creation of the mission logo, see Fig. 1). The atmosphere of common ambition, joy in learning and willingness to cooperate was facilitated by a thoughtful acquaintance program organized by ESA. Indeed, the night before starting the lessons, the students were invited to play the Eco Design game to introduce them to the eco-design of a space mission. It was a treasured occasion not only to be aware of the environmental impact of a space mission, but also to get to know each other.

During the first day of the workshop, ESA's experts illustrated the mechanisms behind the Concurrent Engineering method and made the students exercise with the Open Concurrent Design Tool (OCDT), which is used by ESA in professional CDF studies. On the second day, the students started to perform some initial analyses and outlined a first mission scenario, whilst the demanding requirements arose several design issues.

Fig. 1 - Left: ESA Academy's Concurrent Engineering Workshop in May 2018. Right: Mission logo designed by students

However, after two days of cooperation, sharing and plans modifications, a second iteration was successfully concluded and a coherent "low-cost" mission defined. Results were presented to ESA's professionals: the satellite was shaped as a nail, to keep the rover safe in the head of the structure during the impact on the Moon's South Pole. The rover would then be deployed to explore the lunar surface while being connected to the satellite with a cable to transmit data to the Earth.

III. BENEFITS OF PARTICIPATING IN THE WORKSHOP

Participating in the CEW May 2018 has offered valuable teachings and a precious insight on a realistic mission design environment. The most meaningful lessons learned are reported in this section:

- Creativity naturally stems from diversity (i.e. a team of people with very different backgrounds), and becomes innovation when it is goal-oriented;
- Flexibility, fast adaptive reasoning and a sharp sense of compromise are necessary skills in concurrent engineering, especially when contradictory requirements arise during the sessions;
- Cross-communication ability and trust are the first steps to successfully establish bonds among representatives of different disciplines, thus significantly increasing the efficiency of the design cycle;
- Bearing in mind that everyone depends on the data from others can help in better focusing on generating reliable and reasonable data in very short time periods;
- A proper balance between leadership and listening capabilities is required to make the design proceed;
- One team member should be charged on periodically checking the shared documents status to have a realistic appraisal on how things are getting done, while keeping up-to-date the information on his/her subsystem;
- The concurrent approach and acquired mindset can be applied in our every-day life activities;

Furthermore, it should be noticed the acquired skills and network of contacts last even after the workshop, being possibly the starting point of prospective collaborations and projects.

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IV. Concurrent engineering approach in different areas

In this section, the application of the Concurrent Engineering methodology to different scientific areas is discussed based on each author's point of view.

A. Management of Several Research Activities

While pursuing her studies, Federica from Sapienza University of Rome carried out multiple team-oriented extracurricular activities to gain practical knowledge into the methodology behind the structural design of space systems. In this regard, ESA's Academy program played a fundamental role in her professional development. She garnered considerable hands-on experience by taking care of the end-to-end mechanical design, analyses and testing of STRATONAV experiment for the SNSB/DLR/ESA BEXUS program. The project was successfully launched in October 2016 from the SSC Space Center in Kiruna (Sweden). She also cured the PDR level structural simulations for LEDSAT CubeSat of ESA's "Fly Your Satellite!" project. Interested in space systems design cycle, she was involved in a Concurrent Engineering study at the Concurrent Design Facility (CDF) of the Italian Space Agency in Rome as thermal control designer. However, it was only thanks to ESA Academy that she had the opportunity to apply such methodology to her main field of study, thus leading to improve her productivity during her PhD program to design an advanced integrated control system for vibration damping in large space antennas [2].

The concurrent engineering method changed the way she approached to both her PhD project and related activities. In the first case, the methodology came to use when designing an integrated system for attitude and vibration control as different scientific areas were to be coordinated: structure, control, power, mission analysis. Furthermore, as she is currently involved in several research programs, she has to constantly share and coordinate data exchanges and actions among different groups of people. Her management skills were utterly improved when she drew inspiration from the OCDT software structure. She resorted to Google Drive to organize the activities, create shared folders for each project according to subsystems, documents (i.e. reports, minutes of meeting, etc.) and actions/tasks to do. She found out referring to a shared Google file updated in real time by each team member has drastically reduced the time related to exchange information via other platforms. Furthermore, she uses it also to easily share files from CAD models and FEM analyses tools and directly edit them in the Drive folder. Thanks to ESA Academy, she practically learnt how to improve time management, solutions exchange and document compiling.

B. Sperimental Problems Prediction

In his career as Ph. D. student in Mechanical Engineering, Francesco from Sapienza found Concurrent Engineering approach extremely useful when he had to design a new experimental setup consisting of two plates connected by two nonlinear springs. He needed the method to study the effect of the nonlinear connections on the response of the coupled structure, evaluating its nonlinear normal modes. Concurrent engineering has been fundamental, since its use allowed him to already foresee and prevent some issues that would have arisen during the experimental phase. The crucial step of the design, where the Concurrent Engineering method has been effective, was the shaping of the springs. The nonlinear spring is the key element since it is responsible for the nonlinear vibrations to be measured on the final assembly. During its design, different shapes have been proposed to increase the effect of the geometric nonlinearity, thus obtaining high varying stiffness even for low deformations. However, fatigue effects and manufacturing process have been considered simultaneously, to choose the proper material and thickness that could be feasible with a reduction of costs. The final design has led to an M-shaped spring, 0.5 mm thick and made up of harmonic steel, satisfying all the previous requirements.

The workshop experience has been significant to learn how to deal with someone's other ideas and evaluate whether they are applicable to the current situation or would be ineffective to the observation of the studied phenomena.

C. Organizational Perspective in Artifical Intelligence

In parallel to this project, Javier from University of Cincinnati continued his training in Fuzzy Artificial Intelligence (AI) applied to aerospace systems. The tools provided by ESA have enabled him to work effectively in large teams, where the organizational system is vital for the success of the project. In particular, he applied these insights in the development of an algorithm that ratifies the coherence between the data obtained from all the sensors of a given system during his Master thesis. He fully created a Coherence Package (developed in MATLAB) and tested in a real scenario of the sensors + actuators + human factor system of the Boeing 737 MAX, where case studies and action-to-take decision-making were performed by the algorithm.

The lesson learned that affected the most his work was the organizational perspective when coding the algorithms. It is crucial to have a clear mindset to fully understand the scope of the function and not get lost in intermediate steps. The participation in ESA Workshop helped him in the management of his task, separating the workload in packages and thus to be able to assess them better. Moreover, according to Javier, being up to date with all the individuals of a time was a major challenge during the workshop. A minor change implied a great consequence in the rest of the group. That is why it is crucial also when coding an AI software to have a common up-to-date reference where keeping on working.

D. Development of an Instrument for Lunar Soil Volatiles Characterization

Before participating in the ESA Academy CEW May 2018, Mattia was employed at OHB System (Weßling) for his master thesis. He was the responsible for the overall LUVMI-VS (Lunar Volatile Mobile Instrumentation – Volatile Scout) instrument [3] and designer of the Volatile Sampler subsystem developed under the Horizon 2020 program. Due to this, the instrument had to be designed in a flexible way to be compatible with different lunar landers (Alina 2, Peregrine Lander, Israeli Lunar Lander) and rovers (LUVMI, LUVMI-X). To achieve this, several concurrent design activities were carried out internally and externally together with the different partners.

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The experience he matured at the workshop was crucial in this sense: he understood the strong interaction between the different subsystems and how to discuss choices with all the disciplines while keeping an open mentality approach. The most important concurrent engineering session was carried out after the ESA Workshop. This session took place in the ESA-ESTEC facility. Thanks to the workshop, he was already confident with the system in use and he could fully dedicate to the implementation of the data in the database. As a result, the instrument successfully entered to be part of the studied mission. He is now employed fulltime at OHB as a mechanical development engineer with focus on opto-mechanics and he is constantly referring to ESA Academy's teachings in his everyday working life.

E. Concurrent Engineering for Wastewater Treatment

Apart from making a PhD in wastewater treatment in microgravity conditions [4], Anna from Wroclaw University of Science and Technology is working on projects from various environmental engineering sectors. These projects require coordination of many areas, i.e. Heating, Ventilation and Air Conditioning (HVAC), sanitary installations, electrics. After the CEW May 2018, she familiarized other employees of the company she is working with (a polish company mostly designing ventilation and environmental systems) with these techniques. None of them had previously used it and unanimously stated that it could be a very useful work tool. Indeed, in the design of environmental systems each system might heavily influence the others and a Concurrent Engineering approach can significantly help to create statements (e.g. with the required total power for a building and to redistribute it among different subsystems).

As she is not a typical PhD student in space engineering, she was very afraid that her knowledge would be insufficient and would clash with widespread criticism. However, teachers and other participants never criticized, but they conducted an open, friendly discussion. Such an environment has allowed her to gain knowledge in new fields in a stress-free way. The workshop showed her that the most important features in a space field are not only knowledge, but also people, interdisciplinarity and open-mind.

F. Fundamental Training for the Systems Engineering

Now that he is working as a Systems Engineer, Ferran from DAS Photonics is getting the chance to apply everything he lived during the CEW May 2018 every single day. Not only the technical aspects, but also and foremost, all the knowledge and experience learned regarding teamwork and interpersonal processes. Having the possibility of working under such a multicultural environment, mainly focused in the information exchange, was one of the most enriching experiences he has ever had and, certainly, the lesson that most affected his career. Discovering the best approach of sharing data efficiently while communicating effectively changed completely his way of working.

G. Lessons learned in University and ESA Academy Projects

After the CEW May 2018, Lars from Delft University of Technology has used the acquired knowledge in the Stratos III [5] and SPEAR projects of Delft Aerospace Engineering, where it proved to be a very effective way of keeping track of requirements and design changes, but also to better see the impact that different subsystems have on each other. This latter is also his biggest lesson from the CEW May 2018: in a complex system, every subsystem influences the other subsystems, and one cannot design one, without considering the other subsystems.

During the workshop, he learned of the existence of other ESA Academy projects such as REXUS/BEXUS. Later he proposed a new project within the Parachute Research Group (PRG) Of Delft Aerospace Rocket Engineering (DARE). This new project had the goal to flight test the Stratos III and IV drogue parachute at supersonic conditions. This new project became the Supersonic Parachute Experiment Aboard REXUS or SPEAR in short. During his time within the SPEAR project, he could apply the knowledge acquired during the CEW May 2018, and he learned to interact with a launch provider. During the REXUS/BEXUS project, the team and he learned how to properly approach to design reviews and learned got more insight into how the space industry works.

H. Wider View for a System Engineer

Andreas from the University of Stuttgart has compared different system engineering methods (Subversion, Git, IBM Collaborative Lifecycle Management, Aras Innovator) during his Bachelor thesis and now he has just presented a final thesis concerning autonomous systems control. As he had concerned himself with other approaches to system engineering, testing the ESA system first hand was a very useful process. This helped him understand the challenges for a concurrent engineering platform better and provided him with ideas on how to tackle problems like data availability and integration and contradicting requirements. For instance, in order to know how accurate a control system needs to be, he generally needs data from trajectory planning and sensor team. He got insight into how this data transfer is handled via the excel system in ESA developments. The professional from ESA orchestrating the workshop moderated contradictory requirements from different groups and showed how to conciliate different point of views and ideas to achieve a common solution. The most intriguing lesson learned was to achieve the understanding of problems that did not arise in his particular field of expertise in order to modify his own system such that the common solution was satisfactory for all involved disciplines. Keeping the bigger picture in mind and always thinking about how other contributors might be affected by everyone changes during a development was definitely a skill he is grateful to have acquired participating in this workshop.

I. Exchange of Methodologies is Fundamental

Chaggai from Delft University of Technology participated in the CEW May 2018 based on his experience: he noticed that the best ideas during a design process often appear suddenly and require a quick change of direction in the design. After being selected as a participant, he was confirmed in his belief that by applying the concurrent engineering method to a rapidly changing environment, new concept designs and emerging ideas could be easily adjusted to a newborn project to obtain a

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final mission architecture. Learning how to implement concurrent engineering into a project was far from the most important lesson learned at the concurrent engineering workshop. Moreover, the ESA Academy CEW May 2018 creates a very pleasant and stimulating environment in which new insights are obtained. He particularly reminds of a discussion he had with the participants on how they would approach a problem. The way they approached the problem was vastly different to his personal methodology of naturally taking inspiration from the surrounding environment. A much more rigidly structured approach was pitched to him, leading to vastly different creative ideas to the same problem. Lastly, during the workshop Chaggai noticed that he really enjoys working on complex problems in a high-paced development role. Based on this he decided to start his career as a mechanical engineer in the R&D department of ASM.

J. Inspiration for PhD Program and Future Career

Christopher is a PhD student at University of Surrey and he believes that attending and completing the ESA Academy CEW May 2018 was a truly rewarding and inspiring learning experience. It allowed him to develop a much deeper respect for the challenges involved in the design of space missions and new spacecraft concepts and gave him a new perspective on the exceptional things that can be achieved when people, of differing expertise and priorities, work together as a coordinated team.

His experience at the training course can be credited for a multitude of positive changes in his academic studies, career aspirations and personal life. His desire to pursue a career as a spacecraft structures engineer was solidified by his experience as part of the spacecraft structures and mechanisms subsystem team during the workshop. Through discussion with the diverse group of postgraduate student participants he was inspired to study a PhD in aerospace structures and is now studying a PhD at the University of Surrey in the design and optimization of smart multi-stable composite structures for aerospace applications, with a keen desire to pursue a career in aerospace structures research. It has also opened his mind to the idea of pursuing such a career elsewhere in the world, not just exclusively in his home country.

Since completing the course, he has applied the concepts of concurrent engineering to a number of academic and extra-curricular activities, most notably during the design of the University of Surrey rocket for the UKSEDS National Rocketry Championship. The respect for multidisciplinary design developed through an understanding of concurrent engineering has also been invaluable to his PhD as the project involves a number of disciplines such as aerospace, materials, electrical and electronics, and control engineering.

K. Team Activities Management for Satellite Simulators

Laurentiu from Terma GmbH is currently working as a software engineer, developing satellite simulators that are used mainly to train satellite operators. He also participates in a research project at University Politehnica of Bucharest, in the field of space launch vehicles named "Advanced Control Techniques for Future Launchers". He can mention the usefulness of the concurrent engineering concepts while working within the university research project, where he is part of the guidance team, tasked with developing the guidance subsystem for a future launch vehicle. This subsystem was developed in parallel with the control subsystem, and as a result, the concepts of concurrency came to play. The collaboration between the two team became paramount, especially during the development of the requirements and also of the validation methods. Within the satellite simulator project, a large team has to achieve a great level of synchronization, thus the concurrent engineering aspects arise at a great time. While developing the models, the team members must collaborate in order to efficiently set the functional requirements, and subsequently write the code for the models.

V. CONCLUSIONS

To conclude, being able to apply a new understanding of the concurrent engineering approach and prior knowledge of space engineering to design the mission architecture of a realistic and challenging space mission was a unique educative experience. Finally, the training course was an incredible opportunity to network with likeminded people across Europe aspiring to become the next generation of space engineers and scientists. In this regard, the authors of this paper are also starting to cooperate to found a start-up. They have been so profoundly inspired during the workshop they have decided to improve the design of the rover of LIAR mission in the frame of the ROVERSPACE start-up, starting from applying their layout concept of air-less tires. Their highest ambition is to deliver new ideas into the market, but also to create partnerships that will, most likely, last way beyond this project and will be of benefit for all of them throughout their careers.

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Fly a Rocket!

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***Abstract*— Over the course of one week at the Andøya Space Center, Norway, a university student team of 23 members of some 12 nationalities from across ESA member and associated states participated in a campaign to launch a Mongoose-98 sounding rocket with a suite of sensors with the intention of collecting data from the Earth's troposphere. The rocket itself achieved an apogee of 8.7km and enabled the team to collect data pertaining to parameters such as magnetic field strength, acceleration, light and temperature. The project allowed the students to expand their knowledge of rocketry and orbital mechanics. It gave them otherwise unattainable experience.**

Keywords*— *ESA Education; rocketry; sensor experiments; assembly process; educational process

I. What is the "Fly a Ricket!' Prorgam?

Fly a Rocket! campaign is organized by ESA Education, Norwegian Space Agency and NAROM. The program offers a chance to early university students to learn about rocket science and to assemble and launch their own rocket from Andøya Space Center in Norway. During the program, the students have to complete two assignments about rocket science in order to get ready for constructing and launching the rocket in Andøya. Fly a Rocket! gives a chance for students to work both individually and as a team. The campaign team consisted of four groups, each with specific roles:

- GPS and Simulations

-Telemetry and Data Readout

-Payload Group

-Sensor Experiment

II. Online assignments

As part of the project, the students have been given access to an online course that they could study and use to complete two assignments. In the online course one could read about rocket engines, satellite orbits, as well as the details about the NAROM student rocket. The first of the assignments was mostly about rocket engines and the second one had several questions about orbital mechanics. Both of the assignments helped tremendously with preparation for rocket launch and assembly.

The difficult assignments could only be solved thanks to cooperation between all the students.

III. Assembly process

The experimental set-up for the campaign consisted of two aspects: transmittance and reception. The transmittance was led by the Sensor Experiment Group, who created several sensors, along with the GPS and Simulations Group which, when installed by the Payload Group, sent data from the rocket. The group used a fully stocked workshop with specialized workbenches appropriate for building each sensor. In the room next door, the student telemetry station dealt with the reception of signals, led by the Telemetry and Data Readout Group. This group was tasked with the rigging and calibration of the telemetry station which used a horn antenna to receive signals from the rocket. These signals went through various steps and required the group to program decoders to interpret the signals into intelligible information.

IV. Results

The rocket itself achieved an apogee of 8.7 km and enabled the team to collect data pertaining to parameters such as magnetic field strength, acceleration, light and temperature. The launch and flight phases were nominal even though the student-built GPS system failed to transmit any data to the telemetry station. Below, results from chosen sensors are outlined in detail.

A. Light Sensor

The light sensor was integrated in order to determine the direction and rotational velocity of the rocket. This was achieved by placing the light sensor directly beneath a hole in the rocket, close to the bottom of the payload. When the rocket was launched, depending on whether or not the light sensor had a large spike in voltage or a small spike in voltage first, it could be determined which hole the sun saw first, and therefore the direction of rotation can be determined.

As seen in figure 1, a graph comparing Time (s) and Voltage (V) from the light sensor, each spike represents when the side of the rocket with the holes turned back towards the sun. The time between each spike is about 0.05 seconds. This then totals to about 1000-1200 rotations per minute on average through the entire launch.

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B. Pressure Sensor

The pressure sensor provided a reliable way of determining altitude of the rocket during flight. The sensor contains a piezoresistive transducer which responds to the pressure difference with respect to the internal reference pressure. The analog output voltage of the sensor is proportional to the applied pressure.

Using the sensor output value before launch as the ground pressure ensured the altitude information about the flight was calibrated. Data analysis showed the rocket reached the maximum altitude of 7985 m above the launchpad and the total flight time was 85 s.

C. Magnetic Field Sensor

A KMZ51 one axis magnetic field sensor was used to determine the rotational velocity of the rocket. To get usable data, steps were taken to ensure that the direction of the sensor was perpendicular to the rocket's travel-direction. The sensor did not measure the exact strength of the magnetic field, but it measured the differences in strength and displayed this in the output voltage as the field weakened and strengthened while the rocket was spinning.

The graph of the rocket spin (figure 2) reveals that while the rocket's engine is on, the rotational velocity increases rapidly (up to about 17 spins per second). When the thrust is stopped, it declines with the rocket's velocity until it reaches the max altitude. From there, the rotational velocity increases to what appears to be a somewhat stable velocity of 4-5 spins per second, until contact with the rocket is lost.

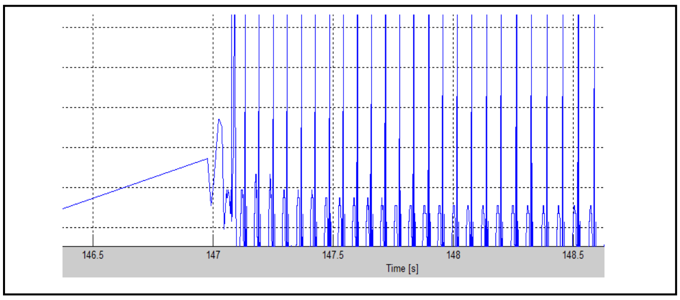

Fig. 1. Voltage vs Time graph

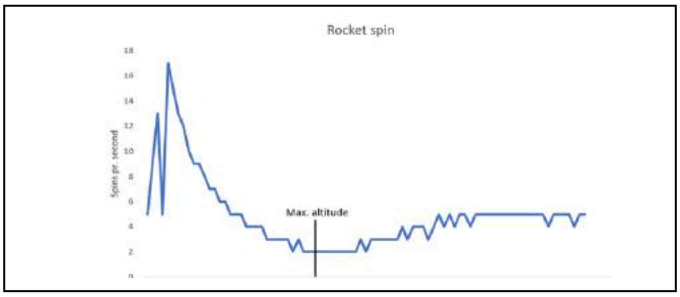

Fig. 2. Spins per second vs Time

V. Educational Process

The students were able to experience almost every aspect of how a rocket is launched from the initial briefing and construction through to the launch and the post-launch data presentation. During the launch itself, the students assumed the roles of the rocket range staff. From the Principle Investigator, to Head of Operations, they got the chance to experience what it is like to work in a space center. During the week the students gained a lot of valuable insight they would not have been able to gain from any other program as this was a unique experience for everyone. The students were able to successfully obtain data from the rocket and the simulations.

The various lectures that the students attended throughout the week at the Andøya Space Center were a unique learning experience, as they were all led by scientists who work in the rocketry field on the daily basis. The knowledge gained from those lectures is one of the most beneficial aspects of the program.

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Touring space science: the HABIT Tour experience

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The HABIT Tour is one of the activities within the strategic activity of GAS to communicate science: a science communication experience that propose a new way to engage people with space science and technology. The HABIT Tour is an itinerant innovative low-cost outreach exhibition to engage society in in situ different kind of audiences. With this activity, we try to build a face to face and a digital community around a space instrument whose one of the main goals is to produce liquid water on Mars within the ExoMars 2020 mission. In this paper we explain some of the mains challenges, opportunities and results of the experience that can be useful for future space engagement and learning activities.

Keywords—HABITt; ExoMars 2020 mission; Open Space Science; learning co-creation; Habitability, life, water, Planetary Protection, space technology.

I. A SPACE INSTRUMENT AS A SCIENCE TOUR

Since March 2018 the Group of Atmospheric Science (GAS) [1] of Luleå University of Technology [2] is developing a new science communication strategy based on *an* ***itinerant*** *innovative low-cost outreach* ***exhibition,*** with the presence of researchers, that allows the direct contact between researchers and audience. The key point of the strategy is to create the conditions for a reciprocal benefit. From one side the experience should help the researchers to evaluate their capability to reach successfully different audiences; and can provide the possibility to audiences to interact directly with researchers and change their perception about the social role and relevance of researchers. Moreover the experience can help audiences to think in terms of logics, and how to use and apply scientific methodology in their everyday-life, how to analyse, verify information, classify, relate, and evaluate the world around.

The strategy integrates some key points: a personal researcher involvement, a research project to be shared, an audience research centered and a feedback to the researchers. The strategy is adapted to different kind of audiences, such as children, young people, families, journalists, digital audiences and influencers, groups with special needs or artists. The strategy permits different approaches to achieve different goals as improve science and technology vocations in young people, facilitate the dialogue between researchers and companies, cooperate and support institutional changes to give researchers efficient incentives to communicate science, design new research policies, or increase the relevance of researchers social role.

One of the possibilities of this strategy is to include early educative levels, as preschool, stimulating children with real (but adapted to their level) science. Some years ago universities all over the world started to interact with high-school students to be more visible and accessible to them. Later on, universities attracted Primary School people with Fun- Fairs, Open Days and "door-to-door" visits. Today universities are expanding their influence and interaction to preschool levels and that is the point where GAS science communication strategy appears.

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Luleå University of Technology (LTU) is a young university placed on the north of Sweden focused on the creation of innovative learning and researching ecosystems and methodologies. One of the strategic areas is the space research and the space prototyping, taking advantage of the presence of fundamental space infrastructures as the European Space and Sounding Rocket Range Space Center (ESRANGE), business incubators as LTU Business AB, specific space educational university training in Kiruna and Luleå Campuses, or high school training in the Rymdgymnasiet in Kiruna, a space curriculum centered high school.

GAS is a LTU research group focused on the study of Earth and planetary atmospheres and the development of instruments for Earth and planetary exploration: from idea to instrument design, development, calibration, operations and data analysis. GAS is a worldwide repute cutting-edge planetary research group with articles in high-impact hournals as Nature, Science, PNAS… The senior members of GAS provide assessment to international space organizations: ESA, JAXA, NASA, EUA and are members of ESA, NASA, ERC panels. GAS has a very relevant role in Educational programs in Space with the largest number of participants in ESA Academy programs of all Universities in Europe in 2017.

The HABIT (HAbitability: Brines, Irradiation and Temperature) instrument [3] proposed by Prof. Martin-Torres and Prof. Zorzano from the GAS was selected by the European Space Agency to be one of the two European instruments on board the ExoMars' Surface Platform (the Russian contribution to the mission). The Flight-Model of HABIT was delivered to the ESA Office in Moscow in July 2019. The main scientific goals of the instrument are:

1. To provide environmental information at the Landing Site.
2. To demonstrate liquid water formation on Mars.
3. To test an In-Situ Resource Utilization technology for future Mars exploration.

HABIT will contribute to one of the main goals of the ExoMars Program [4]: "to search for signs of past and present life on Mars". It will open ways to start planning future manned missions to Mars by serving as a first step in the development of the technology to produce liquid water on Mars, one of the main resources which a prospective crew will need to explore the planet.

Usually space technology, and all the science around it, is seen as a "black box" by society. It is something distant, maybe interesting but incomprehensible, strange, difficult to understand, something done by experts only for experts, something that you can see on TV or internet only as mere spectator without no chances to meet, to touch, to use as a learning tool to be meaningful in everyday life people.

The HABIT Tour [6] is one of the activities within the strategic activity of GAS to communicate science: a science communication experience that propose a new way to engage people with space science and technology (S&T). The As if HABIT were a "Rock'n Roll Star", our HABIT exhibition is showing off around Sweden, home of LTU. The HABIT Tour try to "break" this S&T people's perception in Sweden, developing a very special way to share cutting-edge space knowledge with different kind of audiences such as university and high school students, families, children, journalists, space fans, maker communities, companies etc... Our purpose is to build a national proud on science activities like HABIT, that will be first ever Swedish science instrument to land on Mars [5].

II. OPENING THE SPACE SCIENCE BLACK BOX

A. A three steps methodology to start the conversation with the audience

We have followed a series of steps to be visible and engage our target audiences with our open content:

· Step1: The space technology goes out the laboratory and looks for the audience. That's the touring approach. We transform the space technology in a character that "visits" the country as a music star does in a concert.

· Step 2: People start a conversation with the space technology, a dialogue. They can touch it, use it to learn science in family, class, at home etc…, they can create their own HABIT instrument customizing it, creating it, developing new applications, relating it in different ways with their everyday life. It is the Hands-On and Do It Yourself approach, opening the technology to all the audiences to emulate and reproduce it using 3D printers, software and open technology in general etc.

· Step 3: People create a HABIT Community in schools, universities, science and culture centers, fab labs, maker spaces, airports, libraries, or at home using HABIT for things completely different as it has been planned. HABIT is relevant in their everyday life to do something unexpected and they share it with other audiences and with us giving creative feedback and engagement. The HABIT instrument is something meaningful and interesting in their everyday life that can be used to learn, research, create or make friends. In this stage the long journey from the laboratory has finished. But also starts the most exciting part based on the audience's feedback.

B. Goals and associated indicators to measure the audience impact and engagement

The HABIT Tour is part of the broader GAS Open Science strategy. Is a good example of an "expertise science" transformed in "science for all". The main goals of the HABIT Tour are "under the umbrella" of the general GAS communication strategic goals.

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Each one of the specific goals has their specific indicator to measure the level of achievement reached:

- To transform a "black box" space instrument in a science national icon. Indicator: Media and social media impact.
- To develop a low-cost (about 6.000 €) outreach resource very easy to move, to install/uninstall and to adapt to different kind of audiences with different interests and backgrounds. Indicator: Budget and different kind of audiences involved.
- To create and share an interesting and inspiring story related with space discovery and exploration. Indicator: number of educative guides and workshop materials downloaded.
- To share HABIT and space research as a knowledge experience open to audience´s curiosity and creativity. Indicator: number of 3D Prints prototypes created.
- To improve scientific and technological vocations in children and young people. Indicator: number of high school students registered in LTU.
- To create an increasing social expectation and interest about the instrument until July 2020 (date of mission launching- the launch will be broadcasted live in Luleå). Indicator: number of people up-to-date with HABIT.

III. ON TOUR

The HABIT Tour is conceived as a simple and friendly outreach resource that goes out to meet people to provoke them an experience of curiosity and passion improvement about Mars. In that sense is a flipped outreach tool but a very flexible tool too.

When we design the first edition of the Tour we kept in mind all this to guarantee the contact with the specific target audiences was planned: children and teenagers, educators, makers, science fiction fans, university space engineers, curious families and curious minds in general. First it was the target audience, then it was the place to find them.

In the first edition the HABIT Tour is visiting ten different locations inside and outside Sweden. The locations were chosen following the next criteria:

· Target audience presence.

· Science engagement profile (especially in space arena).

· Prestige and background.

· Media and social media impact.

· Networking.

· Combination of classical and more innovative outreach and learning institution profiles.

The HABIT Tour first edition –from November 14th 2018 to November 14th 2019- is shaped by ten different locations:

· Luleå tekniska universitet.

· Umeå University. Umevatoriet (a Science Center).

· The SciFest of Uppsala University.

· The Space week of KTH Space Center.

· The International Science Festival in Gothenburg.

· The Malmö University.

· Luleå Hamnfestival.

· Luleå Airport.

· National Space Center. Leicester UK.

· New Scientist Live Festival. London.

· Luleå Kulturens Hus.

The second HABIT Tour edition –from November 15th 2019 to July 2020- will be hosted in:

· Ice Hotel. Jukkasjarvi, Sweden.

· Rymdgymnasiet Kiruna, Sweden.

· New Scientist Live North. Manchester. UK

· Lindholmen Science Park, Sweden.

· The International Science Festival in Gothenburg

· Innovatum Science Center, Sweden.

· University of Lund, Sweden.

· Experimentarium. Denmark

· Luleå Hamnfestival (launching broadcast event).

The agreement with all the partners who are interested in HABIT includes the acceptance of the cost of shipping from the previous place, the installation/uninstallation, media and social media coverage and the preparation of a results report at the end of the stay. We provide the partners with all the materials (including a mediator guide, a set of educative guides in Swedish/English for two levels, 7-11 years old and 8-16 years old, a workshop materials and a 3D Print HABIT Model guide), some training for the people in charge and the schedule management.

The HABIT Tour content is a tailor-made box which contains several resources to interact with the audience:

- A set of roll-ups with big size Mars images and some claims like "Water on Mars".
- A screen with a short video explaining the making off of the instrument by the researcher on charge, Chair Professor Javier Martin-Torres.
- A display with a challenge for the audience, a quiz with three representative objects they can relate among themselves: a dry dehumidifier (which reproduces in some way the same "water capture" mechanism of the salts in the HABIT vessels), an exact replica of the instrument and a greenhouse mockup (as an example of future potential in situ uses of the hydrogen and oxygen on Mars). This last resource was made by

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kindergarten five years old children imaging how will be the life of plants, trees and insects on Mars.

The installation includes a couple of QR Codes to download a survey for educators and general audience feedback. It can be installed and uninstalled in 10 minutes.

The HABIT Tour can be used in two different ways:

· As an autonomous little exhibition that can be visited in 15 minutes.
· As a scenario to interact with the audiences in a non-stop way or in a programed way with workshops, hands-on laboratory experiences, sessions of storytelling and gamification for children and families etc…

IV. SOME RESULTS AND CONCLUSSIONS

A. *Quantitative results*

From the opening of HABIT Tour (November 14, 2018) until July 1st 2019 the main quantitative results are:

- Number of engaged people: 43.245 people (including children, teenagers, university students, educators, journalists, space researchers, science communicators, families, makers, astronomy associations and open technology fans).
- Number of digital educative resources downloaded from the HABIT Tour website: 281.
- Number of active HABIT Tour followers in social media: 51.
- Number of workshops done: 7.
- Number of Spin-off projects –do your own HABIT model to improve it in some way-: 6 (one from a ten years old children, 2 from high school students of Stockholm related to architecture on Mars and 2 from high school teachers).

B. *Qualitative results*

Beyond the numbers we have tried to create in the different audiences a specific experience. The main aim was to improve their curiosity about exploration, discovery and experimentation using the space technology.

We use the results obtained in the surveys to evaluate the impact of the initiative are pretty positive although there are some fields to improve.

The survey measured the experience with 22 different items related to the content, the people in charge to attend the installation, the communication, the organization and the global experience. The respondent can choose values from 1 (inadequate) to 5 (very good).

· Contents

- The content has been relevant, interesting and inspiring to me.
- I have learnt some important science concepts.
- I have changed my previous conception about the topic.
- After the activity I will continue researching by myself about the topic.
- I will apply the content in my everyday life.

· People

- The communication skills have been good.
- The scientific competence was good.
- The people of the activity has been able to engage me from the beginning
- They open my point of view and my curiosity about the topic
- They use the appropriate language

· Organization

- Previous information about the activity has been appropriate.
- The timing has been correct.
- The length of the activity has been correct.
- The resources and materials used has been useful.
- The manners have been fine and friendly.
- The space and light have been comfortable and adequate.

· Final evaluation

- The global experience has been positive.
- I will recommend it to my family, friends, colleagues.
- If it will be possible will repeat the activity.
- I would like to engage with the organization as science volunteer.
- Besides the topic of the activity and inside space, environment and technology field I like very much.
- Give us some ideas to do next time a better activity.

We collected a total of 23 surveys. In all of them they chosen the values 4 and 5 to mark in 17 parameters.

The items with marks bellow 4 have been: application of the content to the everyday life, the volunteer engagement effect and the change of their previous idea about the topic.

Some examples of the interested showed by the HABIT Tour are:

- Children and families who interacted in SciFest in Uppsala moved to Stockholm to continue the dialogue.
- Astronomy amateurs who were part in a Lysvik Värmland Star Party on March 9th 2019 came to Goteborg Science Festival to invite us to do the workshop to other Astronomy Association in the city.

The networking has been one of the main outputs of the experience.

C. *Conclussions*

- HABIT Tour is a good tested example of low-cost outreach resource with an efficient and balanced ratio between resources invested and impact achieved. In a flipped approach the content goes out and looks for an active audience interaction.

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- It is very flexible because can be adapted easily to different kind of audiences with different backgrounds (science capital [7]) and interests using the set of educative materials prepared for learning and fun.
- One of the most value aspects of HABIT Tour is its open nature: people confirms that they not only can know and understand about the instrument but they can do things with it: creating stories, designing a prototype, starting a educative project, developing a gamer or even a videogame… HABIT goes in the everyday life people's arena to get meaning.
- The importance of the mediator's figure as somebody who is able to start an interesting conversation about Mars habitability with the audience.
- The HABIT Tour is only the first step to build the truly strategic goal that is to build "HABIT communities" involved in space topics.
- The HABIT Tour also inspired in some cases debates about controversial topics as why should be invest so much money in space and not on Earth problems, or some conspiracy theories defenders about our presence on the Moon.
- Interest in space is clearly improved when you look at it from global Earth problems as Climate Change issues.

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Fig. 1

Fig. 2

Fig. 3

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FIGURES

1. HABIT Tour Opening in Luleå University of Technology. Credits: GAS.
2. HABIT Touer in The International Science Festival of Gothenburg. Credits: GAS.
3. HABIT Tour in the Luleå Hamsnfestival. Credits: GAS.

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Gamma-Volantis on BEXUS 28: From the first sketch to the launch campaign

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***Abstract*— It is hard for students to get hands-on experience in the field of aeronautics and to apply knowledge learned in university to actual projects, since space missions are complex, expensive, and take a long time to complete. Therefore, a group of students at the Technische Universität Dresden (TU Dresden) formed the group "Studentische Arbeitsgruppe Raumfahrt Dresden" (STAR Dresden), which focuses on giving students from different study fields the chance to work on space related activities, by taking part in various competitions and student projects, and even hosting events in Dresden.**

Currently, STAR Dresden is participating in the Balloon Experiment for University Students (BEXUS), which is organised by the German Aerospace Centre (DLR), the Swedish National Space Agency (SNSA) and the European Space Agency (ESA). One of the teams selected for BEXUS cycle 12 is Gamma-Volantis, which is implementing a setup for experimental ozone and humidity sensors developed by TU Dresden's Institute of Aerospace Engineering (ILR).

The balloon flight carrying the experiment will take place in October. Until then, the students will be able to work on subsystems typical for space flight missions and will learn how to write a Student Experiment Document (SED). This document is the scientific documentation of the experiment. They will also gather experience of presenting their work, giving presentations in front of the BEXUS board during design reviews such as the preliminary design review (PDR) and the critical design review (CDR), and even in front of potential sponsors. Due to the tight schedule provided by the launch date, the students will also have to learn to cooperate and communicate between the different subsystem teams, and to be organized in order to achieve the desired goal.

This paper will present the Gamma-Volantis experiment and the methods used by the students to acquire further knowledge and experience on space flight missions. It will contain the difficulties arising from the experiment's requirements and the given circumstances under which the project is supposed to operate. The paper will also discuss the different approaches used by the students to solve the problems and how they interact with different parties such as the BEXUS experts or other student teams from Europe. Overall it will summarize the lessons learned by the students and how they expanded their knowledge during the BEXUS project.

***Keywords*— STAR, TU Dresden, Gamma-Volantis, BEXUS, student participation**

I. Introduction

To make space engineering more tangible for themselves, students at the Technische Universität Dresden (TU Dresden) formed the group "Studentische Arbeitsgruppe Raumfahrt Dresden" (STAR Dresden) [1]. This group takes part in different competitions and projects with a main emphasis on aerospace engineering. Gamma-Volantis is one of STAR Dresden's latest projects accepted to REXUS/BEXUS. The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Agency (SNSA). The Swedish share of the payload has been made available to students from other European countries through the collaboration with the European Space Agency (ESA). Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project. EuroLaunch, the cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles [2].

Gamma-Volantis will launch on the BEXUS balloon 28 in October. The experiment's mission objective is to field test and verify the performance of experimental ozone sensors and air humidity sensors developed by the Institute of Aerospace Engineering (ILR) at TU Dresden. According to the BEXUS cycle 12 schedule the students must go through different stages in developing their experiment until it is ready to launch.

II. Experiment Setup

To collect atmospheric data, the GAMMA-VOLANTIS experiment consists of two sensor units and a data processing unit. A sensor unit is made up of 7 different sensors (i.e. experimental ozone sensor with gold electrodes, experimental ozone sensor with platinum electrodes, reference ozone sensor, pressure sensor, experimental air humidity sensor, reference air humidity sensor, temperature sensor) as shown in Fig. 1. The second sensor unit is for redundancy. Both units are mounted to the outer wall of the experiment facing the outside of the gondola for easy access to the atmosphere.

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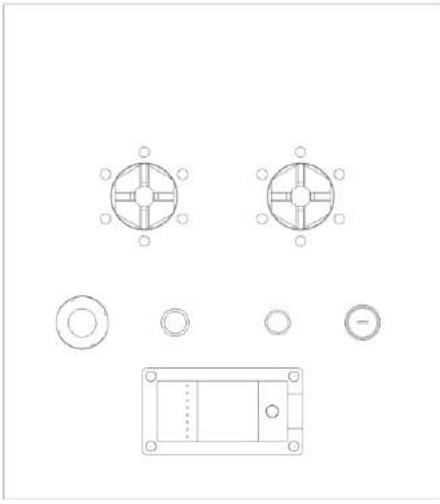

Fig. 1. Sensor unit (Top: Experimental Ozone Sensors; Middle: Pressure, Temperatur, Reference Air Humidity, Experimental Air Humidity Sensor; Bottom: Reference Ozone Sensor)

The experimental ozone sensors developed by the ILR are solid-state electrolyte sensors. Compared to common ozone sensors, they are smaller, faster, inexpensive, and consist of no moving parts. The electrolyte material needs to be humidified to maintain its ionic conductivity, so it is counteracting the cross-sensitivity shown in many other miniaturized ozone sensors. The air humidity sensor provided by the ILR is a new, simple, and low-cost sensor with fast response times.

III. Challenges & Solutions

During the design and assembly phase, the team members encountered many problems that can be assigned to some of the subsystems of the mission:

- Project Management
- Electrical Power System
- Thermal Control System and Structure and Mechanism
- Command and Data Handling Systems

A. Project Management

The mission schedule given by the REXUS/BEXUS organizers includes due dates for reviews (i.e. Preliminary Design Review (PDR), Critical Design Review (CDR), Integration Progress Review (IPR), Experiment Acceptance Review (EAR)) as well as the launch date. Some of the due dates were during exam periods when the students had to concentrate on their studies and working on the experiment became a secondary concern.

Another vital part of the experiment's success is frequent communication between the subsystems because changes in one subsystem can greatly affect others and require major changes in the overall design. Since the team had just formed and the team members did not know each other well, communication was poor and not every member was up-to-date.

For time management, the experts from the REXUS/BEXUS programme suggested the use of a Gantt chart, where a detailed project schedule could be illustrated. This chart was very useful in seeing whether the team was on time or had a delay. By planning the schedule, the students had to take time periods with low productivity, such as the exam periods, into account and work around them.

To increase the team's communication and avoid misunderstanding, the students scheduled weekly meetings and met outside of the university for a barbeque or a game night. This built a strong group cohesion and improved the conversation and information flow between the subsystem groups.

B. Electrical Power System

A major problem with the electrical power system was the missing electrical engineering expertise. The Gamma-Volantis team mainly consists of mechanical engineering students with only basic knowledge in electrical engineering. This lack of knowledge posed a challenge in designing the electronics, particularly considering the experiment's main objectives hugely rely on electronics, as with most space applications. Especially unifying high current power electronics, sensitive analogue circuits and digital data transmission on a single circuit board, all working at very low temperatures, represented a major challenge.

Another difficulty came from the readout electronics provided by the institute because the modification and adaption to the experiment's specific needs required more work and time than expected.

After strictly zoning the circuit board, multiple iterations, and a careful component selection, the students managed to design a functioning, compact circuit board with the help from the institute and through extensive research and testing.

C. Thermal Control System & Structure and Mechanism

The experimental ozone sensors need to be humidified and therefore require a small water reservoir. In the stratospheric atmosphere, the water would freeze and cause the experiment to fail. This problem is why the students had to find a way of keeping the water reservoir at a constant temperature above freezing point. Another main problem was to keep the electronics in their working temperature range and to keep the temperature stable to decrease the risk of failure. The electronics also needed to be properly shielded from electromagnetic interference, as the ozone sensors work with very small currents.

The ozone sensor already had a temperature sensor inside the water reservoir to monitor the temperature during flight. To regulate the heat, heating foils were attached to the outside of the reservoirs with a heat resistant glue [3]. The sensor housing is shown in Fig. 2.

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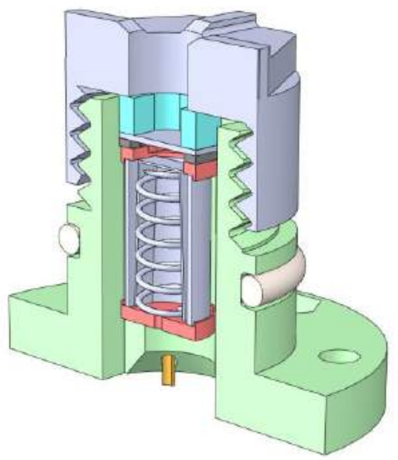

Fig. 2. Sensor housing of the experimental ozone sensor

To maintain the temperature inside the box at a constant level, the box is covered in polyethylene foam and reflecting foil to lower solar radiation. The sensor units facing outside the gondola have an additional polyethylene panel mounted in front of them in order to protect the sensors from the sun as well.

The electronics are stored in a smaller aluminium box inside the experiment to shield the electronic components from said interference. Fig. 3 shows a model of the Gamma-Volantis experiment with the aluminium box inside.

Throughout the process of calculating the heat flux and load distribution inside the experiment, the students greatly increased their knowledge of handling simulation software. They also acquired experience in choosing suitable materials and designing a project that is easy to manufacture and easy to use.

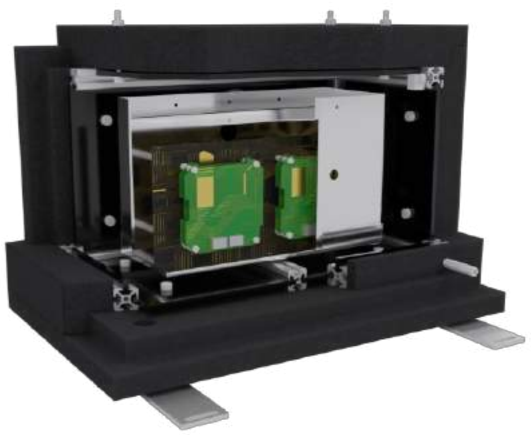

Fig. 3. Section view of the Gamma-Volantis Model

D. Command and Data Handling Systems

Programming code in a group can be challenging without the proper tools. In the beginning, the team members shared their latest progress via ZIP files, which made it hard to keep everyone up-to-date or go back to older versions if an error occurred.

After some time, the team started to use GitLab, a web-based DevOps lifecycle tool, which includes a version management system [4]. GitLab combines versions from each programmer with access and combines them, making the current code available for everyone. This hugely increased the workflow and improved the team's work.

IV. Conclusion

For a young university group such as STAR Dresden, REXUS/BEXUS has been and continues to be a great project to get started in aerospace engineering and give hands-on experience to students. The Gamma-Volantis team members had the chance to get a first glimpse of the typical space project procedures and learned new techniques for problem solving with the help of different experts. The team also presented the experiment's progress to a review board.

For future projects, the team agreed having an experienced student as team leader may increase the communication within the group and might support younger students who are new to the project. It might also be a benefit to include different engineering students with different qualifications, e.g. electrical engineering, since acquiring knowledge in a different area of expertise is time consuming.

V. Outlook

After the Gamma-Volantis experiment is completed and accepted at the Integration Progress Review, it will be shipped to the Kiruna Launch Pad in Sweden, where it will launch on the BEXUS balloon 28 in October. After the flight, acquired data will be analysed and shared with the institute. The team members will continue to work on future aerospace projects and share their experience and knowledge with younger students.

Acknowledgment

The entire Gamma-Volantis team would like to thank Tilman Schüler and Yves Bärtling from the ILR at TU Dresden for their constant support and advice during the project. The team also acknowledges the excellent support from the all the entities involved with REXUS/BEXUS, i.e. DLR, SNSA, ESA, ZARM, and MORABA.

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How cooperation between student groups and universities opens new possibilities for both the students and institutes

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Abstract— **There are many factors that present difficulties for potential student-run space related projects. Although there may be much willingness to work or commitment towards the subject, the long-term nature and complexity of space programs, together with the high costs, generally pose a barrier. Universities give their students many opportunities to gain scientific experience but are limited by their specializations and available funding. These limitations lead to a situation in which students generally cannot easily create new projects, at least not integrated into established structures. Many students want to participate in projects like REXUS/BEXUS but struggle to find like-minded peers, and so their ambitions fade away amidst university stress.**

In order to tackle the discrepancy between project ideas and motivation and the existing structures established at universities, a group of students in Dresden wanted to lay the groundwork for working on their own projects in their own way. As such, they decided to establish a student-led base for space education at the "Technische Universität Dresden" (TUD).

The result was the formation of STAR Dresden. "STAR" is the acronym for "STudentische Arbeitsgruppe Raumfahrt Dresden" which translates to "Student Working Group for Astronautics". The purpose of STAR is to provide a foothold for engaging in space projects of any kind, with an emphasis on independence from university bureaucracy.

Taking as an example the projects of STAR and especially an OOXYGEN experiment, this paper shall demonstrate the importance of student-run projects and groups in universities. A group like STAR Dresden provides a great degree of freedom for both students and universities. A freedom which cannot be offered by the traditional modalities of introducing students to scientific work at university.

OOXYGEN on BEXUS is a collaboration between STAR Dresden and the Institute for Applied Physics of TUD. This project shows how a collaboration between a student-led group and an institution of a university can be mutually beneficial.

Keywords—STAR; Technische Universität; Dresden; Cooperation; Benefits; Challenges; REXUS; BEXUS

I. Introduction

To not simply state theories about the possibilities and challenges of the collaboration of independent, student-led groups and universities and other institutes, specific examples will be explained in the introduction and analyzed and from them a rough hypothesis will be proposed in the following chapters.

A. The Group STAR Dresden

"STAR Dresden" (or simply "STAR") is a student-led group at the "Technische Universität Dresden" (TUD – Technical University Dresden). [1]

The Name "STAR" is an acronym for "STudentische Arbeitsgruppe Raumfahrt", which translates to "student work group Astronautics". The purpose and declared goal of STAR is to provide the groundwork for engaging in space projects of any kind with an emphasis on practical experience and independence from university bureaucracy. Although STAR is an independent organization, the members of STAR are mainly students of TUD and as such STAR has strong ties to many institutes within TUD. These institutes include, although not exclusively, the "Institute of Aerospace Engineering" (ILR), where most members study, the "Bitzer-Chair of Refrigeration, Cryogenics and Compressor Technology" (BIZ), and the "Institute of Applied Electronics" (IAP). The IAP being STAR's partner on the OOXYGEN Experiment.

STAR was founded in early 2018 by a group of around 10 students and is now in the process of becoming a registered nonprofit association containing around 30 members with an interdisciplinary background, although mainly mechanical engineering. The group is funded exclusively via sponsoring, donations and membership fees.

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B. The OOXYGEN Experiment

"OOXYGEN", which is an abbreviation of "Organic OXYGEN", is an experiment developed by a team composed mainly from members of STAR in cooperation with the IAP. The goal of OOXYGEN is to support and test an experimental oxygen sensor built exclusively from organic electronics and developed at the IAP. The Sensor facilitates the bioluminescence [2] of an organic molecule. This bioluminescence changes with different concentration of oxygen in the surrounding atmosphere.

This Experiment is to be a field-test in a realistic "out-of-Lab" environment with the purpose of giving feedback to the developers. The program, in which OOXYGEN is developed and on which it will be launched, is the REXUS/BEXUS (Rocket/Balloon Experiment for University Students) program, specifically BEXUS 28. OOXYGEN accommodates all necessary equipment to remotely and/or autonomously take measurements of the atmosphere during the ascent of the balloon.

OOXYGEN is the sister-experiment of "Gamma-Volantis", which is developed for BEXUS 28 in a similar fashion by a team of STAR members in cooperation with the ILR.

C. REXUS/BEXUS

The REXUS/BEXUS programme is realised under a bilateral agency agreement between the German Aerospace Center (DLR) and the Swedish National Space Agency (SNSA). [3] The Swedish share of the payload has been made available to students from other European countries through the collaboration with the European Space Agency (ESA).

Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project. EuroLaunch, the cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles.

REXUS/BEXUS offers its participants a great platform for engaging in space related and atmospheric research. There is no requirement for the program to have an established group like STAR to participate.

II. Cooperation of STAR and the IAP

The Cooperation of STAR and the IAP for OOXYGEN is very strong but also follows strong boundaries. STAR, i.e. the members of STAR which compose the OOXYGEN team, are responsible for developing and designing the experiment framework, which includes the mechanical support structure, miniaturized measurement electronics, thermal management systems, gas management systems and everything apart from the sensor itself. The sensor, the heart of the project, is in turn developed solely by the IAP. The IAP also provides a great amount of knowledge about atmospheric measurements and provides the sensors to be used in the experiment. Additionally, the IAP contributes laboratories to develop and test separated assemblies and the entire experiment.

Through OOXYGEN and BEXUS, the students of STAR have the possibility to engage in a full-fledged space program with all the challenges and associated lessons to be learned. The IAP, in turn, can test a newly developed sensor and has the opportunity to further analyze the feasibility of the integration of the sensor into a small but reliable measurement assembly. Although the project is still in progress, valuable lessons have already been learned. As the second project of STAR overall, the participation in REXUS/BEXUS with two separate experiments at the same time and cooperation between STAR and the IAP (for OOXYGEN) and ILR (for Gamma-Volantis) tests the structures and concepts of STAR and shows what can be gained from such an undertaking.

III. Possibilities for Students and Universities

A. Students

The main goal for academic student groups is engagement of students; therefore, the main focus is enabling students to gain as many benefits as possible. Forming a group enables students to tackle larger and much more complex projects. Such projects would be too complex for single individuals to accomplish in a reasonable timeframe. Although most REXUS/BEXUS projects are not anchored in an established group and are temporary groups, there is also several experiments that originated from STAR-like groups, e.g. "Roach 2" from "KSat Stuttgart e.V." [4]

With the matter of teamwork, an important lesson of real work life experience can be gained. No space program is completed in isolation. As such, teamwork and interdisciplinary discussions are essential soft skills an emerging engineer or scientist must learn. STAR-like groups are ideal training environments for the development of these important skills. Other soft skills are learned as well, e.g. the grinding search for suitable COTF-components.

Apart from the valuable, although difficult to quantify, practical experience, there also is the possibility of networking inside and outside of the university. Experience from STAR shows us, that some students gain the opportunity to directly work for institutes e.g. as student assistants or to engage in other scientific work apart from the student-led group at the institutes of the TUD. Through such networking, topics for large coursework, which is common at universities, can be generated. Assignments don't need to be "dummy topics", but can instead be real-world problems for projects which the

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students take part in. There are also opportunities to network outside the university environment. During projects of all kinds, contact with component suppliers and their sales engineers is almost always needed and a crucial part in developing a scientific experiment or a product. Gaining experience with such day-to-day affairs during one's studies can turn out to be a valuable soft skill.

All the above can, of course, be gained directly through work at institutes of a university but are easier done as an independent student group in cooperation with a university. This comes from the comparatively unbureaucratic nature such groups tend to have. Just to name an example, student groups don't need to employ (and therefore pay) their members since it is a voluntary membership and generally functions outside, or at least not directly inside, the apparatus of a scientific institution which must obey a very sophisticated legal framework.

Next, never again in their career do students have the ability to freely follow their guts and try a multitude of subjects. Nor will students again have the opportunity to even fail tasks or projects with as few consequences as during their studies. Such failures can provide a valuable learning experience. For students, a failed 1000€ or even 10 000€ project may feel as big as a failed satellite but it is, all in all, still a much more manageable matter.

Last but not least, the self-governing nature of STAR-like organizations enable students to propose projects and then decide together with their peers whether they want to tackle a project or not. There is generally no other institution outside of the group to block a project. There are of course limiting factors like funding or manpower but not many others. To take a real-life example of this, the first project of STAR was its participation in the "European Space Elevator Challenge" (EUSPEC) in 2018. This participation most likely would not have happened if proposed by students to any institute of the TUD. As an independent student group, STAR was still able to participate.

B. *Universities*

STAR-like groups also bring advantages to the institutes they work with. A good collaboration opens a pool of dedicated, interdisciplinary students, willing to work and spend a large amount of their free time for scientific and technical projects. Besides the pretty much guaranteed motivation of the students, self-organization is a valuable benefit of working together. A well-organized STAR-like group can function like a contractor of sorts which gets a task and then shows results without scheduling meetings and managing departments.

From personal experience, the relationship between students of a group like STAR and the university is a very friendly one. This friendly relationship makes working together fun and engaging whilst still being scientifically demanding. Again, from personal experience, university personnel encourage and support student engagement wherever possible.

IV. Challenges of the Cooperation

A very important aspect and challenge for the relationship between student-led organizations and universities also resides in its "free of charge" nature. Both sides must make sure not to misuse the opportunities in malicious ways. These opportunities should always be an addition to the many possibilities a university has but never an alternative to them. Just to name an example, a junior scientist should and must still be employed directly at the university and not be used through a "voluntary" membership in a STAR-like group.

Another challenge lies in the aforementioned independence of the students. Since the students aren't bound by an employment contract at the institutes, it is always possible they lose interest. However. since membership in a STAR-like group generally shows dedication towards space related topics, this possibility may be as small as it would be in a salaried position.

Self-organization, although a great strength, also harbors great risk for a student operated group. If the organizing clique disappears from the group, e.g. from loss of interest or stress from studies, the group can break apart if suitable and dedicated replacement is not found. Granted, the students who participate in student operated groups are likely to be highly dedicated and capable of finding a solution if they want to keep the group active. With that said, care should be taken to always have an influx of new members in order to keep the group active and stable.

Possibly the largest problem for STAR-like groups is funding projects. Since such groups are not integrated directly into their university, they are not eligible for the university's budget and therefore rely on sponsoring and donations. This type of funding makes long term planning difficult and uncertain. Permanent, dedicated facilities for the groups alone are hard to maintain and universities often want to but simply can't afford to help out. From our experience, project bound facilities, most often provided by the university, are therefore standard practice.

V. Conclusion

Although there are challenges which potentially could even lead to the dispersal of groups like STAR, there are great benefits. The numerous possibilities for additions to a universities portfolio of activities make it a worthwhile

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endeavor. The risk is comparatively small and in principle, student-led groups don't even need formal support of their university though real-world experience shows, that university personnel normally support such ambition from students to do more than is expected.

From this I would strongly support the formation and the following activities of any such groups.

VI. Outlook

STAR Dresden will hopefully be a lasting endeavor at the TUD and continue to exploring the fruitful cooperation with many more projects. Apart from the two currently running sister projects, OOXYGEN and Gamma-Volantis, both on BEXUS 28, other projects are already in the feasibility phase of project planning, i.e. a participation at REXUS 2020 and at the European Rover Challenge.

Acknowledgment

Many thanks must be given towards the institution that support STAR Dresden in its workings. Mainly, but not exclusively, those are the ILR, IAP and BIZ.

The REXUS/BEXUS program and its team must be especially thanked, for enabling STAR Dresden to undertake two parallel experiments on BEXUS 28, OOXYGEN and Gamma-Volantis, as well as sponsoring the participation of STAR at this 3rd SSEA.

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CLIMB – A 3U CubeSat to Van Allen belt

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***Abstract* — *CLIMB is a 3U CubeSat whose goal is to reach the Van Allen belt with the help of an advanced propulsion system. Usually, the Van Allen radiation belt is avoided by spacecraft due to its high radiation levels. CLIMB aims exactly for this region to conduct various measurements. The spacecraft's subsystems need to be designed in a way to cope with this rough environment and to ensure that even in case of failure or loss of the spacecraft, it still shall deorbit within 25 years, as required by the Austrian Space Law. Some of the systems of CLIMB have already flown and been qualified during the previous Austrian mission PEGASUS.*

Keywords* — *Clean Space; CLIMB; CubeSat; electric propulsion; FEEP; IFM; magnetic field; orbital debris mitigation; radiation; re-entry; Van Allen belt

I. Introduction

The magnetic field of Earth acts as a shield against incoming radiation from the Sun, as well as from interstellar space: many charged particles that reach Earth are trapped in the magnetic field outside of the atmosphere in the form of rings [1, p. 25], and do not reach the ground. While this shielding effect is beneficial for life on ground, it is detrimental for life in space [1, p. 25] due to the higher absorbed dose [1, p. 44] that accumulates through exposure to the locally increased flux of charged particles [2, p. 214]. The ISS - and with it the main residence for humans in outer space - has an average altitude of approximately 400 kilometres [3]. At this altitude, it is below both of Earth's high-radiation-density rings, normally called the Van Allen radiation belts [1, p. 25].

However, many other spacecraft operate in or at least pass through these regions [4]. As a consequence, details about this environment are relevant for spacecraft design in terms of life time and radiation hardness in general.

Efforts have been made to quantify the radiation levels and size of the Van Allen belts [5]. The shapes of the belts follow the field lines of Earth's nearly dipolar magnetic field (see *Fig. 1*), forming toroidal regions of high fluxes of protons, electrons, and ionised atoms (most notably helium, nitrogen, and oxygen [1, p. 25]. These fluxes decrease exponentially towards the boundaries of the belts. They peak at approximately 10^8 electrons and 10^3 protons per square centimetre and second in the inner and 10^6 electrons per square centimetre and second in the outer belt [2, pp. 214-215].[1] These peaks appear at around 2,000 and 31,000 kilometres respectively, but high charged-particle densities associated with the Van Allen belts have been predicted at altitudes as low as 500 kilometres near the equator and even lower in the South Atlantic Anomaly (SAA) - a region where Earth's magnetic field is unusually weak [5] [1, p. 25]. The AE-8 model predicts an upper limit of the outer belt at approximately 50,000 kilometres altitude [1, p. 28], but exact values vary from source to source (e.g. [6]). This uncertainty may be due to the temporal variations of the belts.

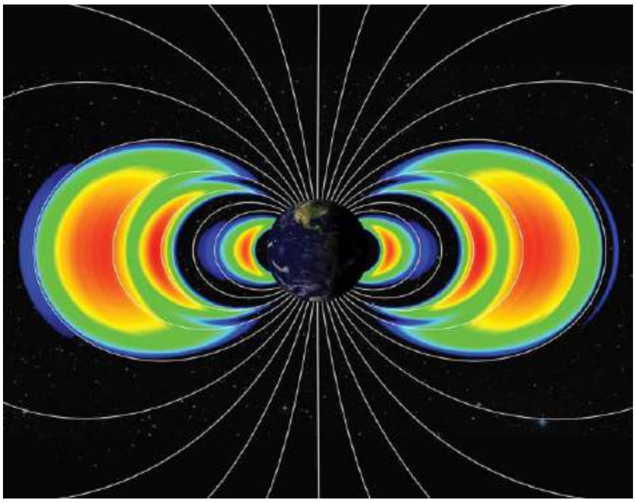

Fig. 1. Schematic visualisation of the Van Allen radiation belts. Their shapes result from the magnetic field lines (white), because magnetic interaction is the dominant force acting on the charged particles that constitute these belts. The image also shows the temporary third radiation belt.[2] **Credits: NASA's Goddard Space Flight Center/Johns Hopkins University, Applied Physics Laboratory**

The academic satellite mission CLIMB aims to probe this environment using a design based on the CubeSat Design Specification. The mission combines commercial components with in-house designed solutions, while building on the

[1] These values consider only electrons with more than 500 kiloelectronvolts and protons with more than 100 megaelectronvolts of energy.

[2] The third radiation belt - a highly transient belt of electrons strongly dependent on solar activity - was first measured by the Van Allen Probes [10].

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experience of the mission PEGASUS (launched by the University of Applied Sciences Wiener Neustadt (FHWN) in 2017). The CubeSat Design Specification describes the volume of a spacecraft in terms of units, where one unit U is a cube with a side length of 100 millimetres.

Despite existing measurements, the time-variability[3] of the composition of the belts provides a permanent motivation for up-to-date data. The use of CubeSat components is one peculiarity of this mission compared to previous efforts (most notably NASA's Van Allen probes).

II. Mission objectives

As indicated above, the main scientific goal of the mission is to investigate the environment in the Van Allen belts in terms of electromagnetic radiation and charged particles. Another important objective is to prove that a CubeSat can survive such a challenging radiation environment without relying on extremely expensive radiation hardened components. Such solutions have already been successfully implemented in the former CubeSat PEGASUS resulting in an extremely low number of reboots or other radiation based anomalies [7].

In addition to that, a recently commercialised electric propulsion (EP) module - a crucial subcomponent - is demonstrated. The mission relies heavily on this component, which is used for reaching the target orbit as well as for active de-orbiting.

As a student project, education of participants as well as academic advance are noteworthy goals of CLIMB. In this context, it should be noted that the available resources only allow visiting the lowest regions of the inner Van Allen belt.

III. Mission description

The mission CLIMB uses a Field Emission Electric Propulsion (FEEP) system in order to reach the Van Allen belt and, upon arrival, conduct various measurements such as measurements of the magnetic field as well as of the radiation levels. Reaching the inner Van Allen belt by means of FEEP is considered a core part of the mission. As a consequence, the spacecraft operates in different orbits over the course of the mission. *Fig. 2* shows the various orbits where the satellite operates, along with their associated mission phases.

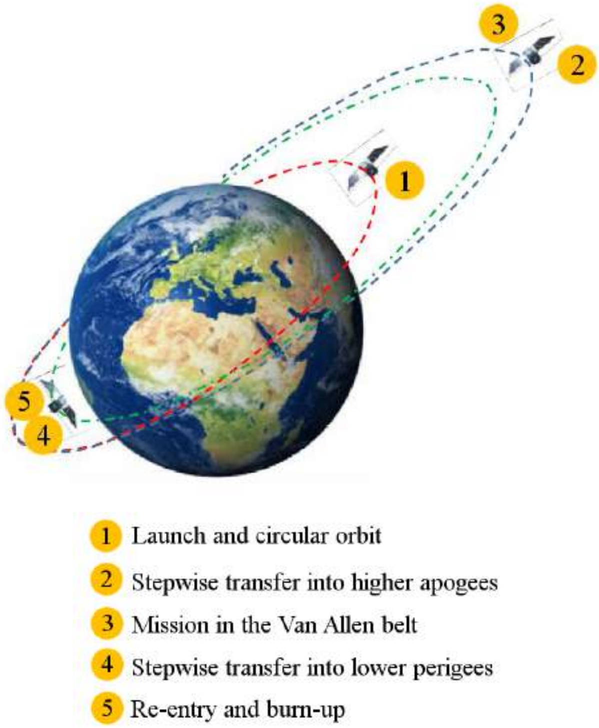

Fig. 2. Schematic depiction of the various phases in the CLIMB mission (orbits are not to scale)

A. Launch and early operation (LEOP)

Following the launch, the early operation phase is conducted. Most of the activities in this phase are pre-programmed including the deployment of the antennas and initiation of the beacon, automatic alignment of the satellite and basic functions of the thermal system.

B. Commissioning phase

During the commissioning phase a complete check of all systems shall assess their functionality. The outputs of all sensors shall be assessed and, if needed, calibrated. In case of anomalies, these shall be investigated to assess the probability and severity of their impact on the mission. Based on this assessment the decision is made whether to proceed with the mission or not.

C. Orbit raising phase

With the help of the propulsion system, the satellite increases its apogee while, in the early stage of this phase, leaving the perigee constant. In frequent steps, a health assessment of all relevant systems (propulsion, power, communication, etc.) is conducted. Only if all operational parameters are within the nominal range, the mission is allowed to proceed. When the apogee reaches a certain value, the satellite initiates a periodic decrease of the perigee while still increasing the apogee. Doing so ensures that the satellite would at any point naturally deorbit within 25 years, so as not to

[3] Especially the heavy ion densities vary with solar and geomagnetic activity [1, p. 25]

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exceed the maximum allowable time in orbit. The final goal of the mission is an apogee with 1,000 kilometres altitude [8].

D. Science phase

The data that are relevant to the scientific objective of the mission (i.e. measurement of the magnetic field and radiation dose) are collected from the very beginning of the in-space operation. When CLIMB reaches the altitude of the Van Allen belt, the official science mission starts and the mission focuses on data collection rather than changing the orbit.

E. De-orbiting phase

In consideration of space situational awareness and the Austrian Space Law, specifically its requirements on orbital debris mitigation, many features have been implemented into the mission concept as well as in the technical design of CLIMB in order to ensure that the total time in orbit is well below 25 years - even in case of a loss of the spacecraft at any time during the mission. The Austrian Space Law requires that every space operator (coming from Austria) has to deorbit or remove[4] their satellite at its EOL (end-of-life) from LEO (Low Earth Orbit). For non-manoeuvrable objects their post-mission lifetime shall not exceed 25 years.

Following the achievement of the scientific objectives, the satellite starts to actively deorbit. This is done in two ways:

- At the apogee, the propulsion system fires in retrograde direction to lower the spacecraft's perigee into the denser areas of the atmosphere.
- In the vicinity of the perigee the satellite aligns itself such that its maximum area (solar array) is perpendicular to the flight direction.

The mission ends with the satellite breaking up and burning up completely in the atmosphere.

IV. TECHNOLOGY

Initially CLIMB was intended to be built upon the novel structure of the previous 2U CubeSat PEGASUS. Though, as both the dimensional and mass limitations were exceeded already early in the design phase of CLIMB, the decision was made to move on to a 3U CubeSat as seen in *Fig. 3*. Nevertheless, the structure is in essence identical to the one in PEGASUS. The main loads are carried by the separate rails in each corner of the CubeSat. The rails are connected by aluminium top and bottom panels and by the PCB (Printed Circuit Board) side panels. The internal PCBs are connected to the side panels only via electrical connectors, which therefore carry the mechanical loads. Some of the heavier subsystems (e.g. Attitude Determination and Control System, battery unit) also have additional aluminium attachment interfaces to the rails. The PCB side panels house the circuitry, which provides electrical interface between internal PCBs and other subsystems. The side panels also serve as a mechanical interface for the solar cells.

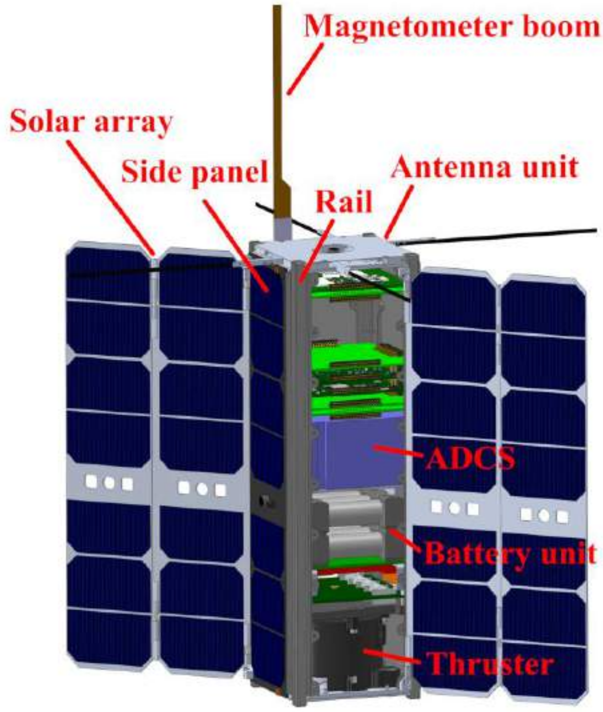

Fig. 3. General view of the CubeSat CLIMB without one side panel.

The main difference between the PEGASUS and CLIMB structures are the length of the rails and the side panels. Also, as the power requirement for CLIMB CubeSat is vastly increased - mainly because of the propulsion system - CLIMB incorporates deployable solar arrays. The thruster requires a maximum of 40 watts of electrical power whilst propelling and up to 5 watts during stand-by to keep the indium propellant in the liquid phase [9]. Also, other subsystems need at least a few watts of additional power. To provide this high amount of power, two double-folded deployable solar arrays are used in addition to the solar cells on the side panels: facing the Sun there are two sets of 7 solar cells on two side panels of CLIMB (nominally at 45 degree angle towards the Sun) and 2 solar arrays, each with 2 solar array elements (plates), each with 7 solar cells, totalling 28 deployable solar cells. The total power generated at peak is approximately 35 watts. For the hinges of the solar array, the usage of commercial fastenings is not possible because of the tight space requirements on the sides of the CubeSat - two packed solar array elements may occupy no more than 5 millimetres of space. The hinges of the solar arrays use the combination of laser welding of aluminium and soldering between aluminium hinge parts and PCB solar arrays.

A. Thruster & ADCS

The biggest subsystem is the Indium FEEP Multiemitter (IFM) Nano, provided by ENPULSION GmbH (shown in *Fig. 4*). The thruster has a wet mass of 900 grams and almost fills one CubeSat unit of volume. By default, the system comes with 230 grams of propellant, which is sufficient for the mission by

[4] Putting the satellite into the graveyard orbit is only allowed for certain orbits, for example the satellite is orbiting at GEO (Geostationary Earth Orbit).

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a large margin. The propulsion system provides a nominal thrust of 350 micronewtons at a specific impulse of 4,000 seconds, with the ability to operate with less power at the cost of thrust or specific impulse. The second largest subsystem for CLIMB is expected to be the Attitude Determination and Control System (ADCS) as MAI-400 (from Adcole Maryland Aerospace, LLC) with a volume of 0.5U and a mass of 700 grams. It features three reaction wheels, a 3-axis magnetometer, two Infrared Earth Horizon Sensors (IREHS), three electromagnets and an ADCS computer for a stand-alone, plug-and-play attitude control system.

Fig. 4. Indium FEEP Multiemitter by ENPULSION GmbH [9]

Precise determination of the orbit is crucial for this type of mission. In order to support the ADCS, a laser ranging system is used. A laser on a ground station sends a high intensity laser pulse to the spacecraft. CLIMB is equipped with reflectors, to send back the laser pulse to the ground station. With the reflected signal, the position of the spacecraft and its orbit can be determined precisely. This helps to plan thrusting times and attitude corrections in a more efficient and reliable way compared to relying on the ADCS alone.

The following parts are inherited from the previous mission PEGASUS with minimal to no modifications or changes: in-house developed OBC (On-Board Computer), PSU (Power Supply Unit) and STACIE-D (Space Telemetry And Command Interface - Delta), commercial off-the-shelf UHF (Ultra High Frequency) antennas, batteries and solar cells.

B. Power & Thermal subsystems

Two sets of battery units, each containing four 18650 type lithium ion rechargeable batteries, act as a buffer for electrical power (e.g. during eclipse times) and as a backup in case there are anomalies with the solar power generation. The already existing PSU needs to be adapted to the higher power requirements and the increased number of batteries. The outputs are 5 volts and 3.3 volts. Additional power converters located on the battery units are used to output 12 volts for the thruster.

Two communication systems are used: the main one operating in the UHF- (STACIE-D) and the secondary in the S-band (STACIE-S).

All the individual thermal requirements for different subsystems must be satisfied. For example, if the temperature would drop below 0 degrees Celsius, the batteries would experience reduced capacity. As a countermeasure, the battery units are placed near the thruster to avoid the need for additional battery heaters. The waste heat from the thruster is directed towards the batteries. However, the batteries also exhibit a shortened lifetime with higher temperatures. If possible, the thermal design would keep the temperature of the batteries between 0 and 20 degrees Celsius.

As the power usage and thus power dissipation is relatively high for such a spacecraft size, a lot of effort is put into the thermal design. Various thermal elements are considered, including heaters, phase change materials, thermal straps, heat pipes, louvres, radiators, multi-layer insulation and different surface coatings. The highest power dissipation is expected to occur on the thruster and the battery unit (which includes converters for the thruster). Both of these subsystems are located at the bottom part of CLIMB. Another high power system, the S-band transceiver, is expected to dissipate about 8 watts of power. Though, as this subsystem is located at the top of the satellite, it might be less of a concern for the thermal configuration. At most, CLIMB is expected to dissipate about 26 watts of thermal power while thrusting.

The temperature ranges are highly dependent on the orbit. In the worst hot case with dawn-to-dusk orbit and calculated from the internal power dissipation, the preliminary estimate for the temperature is around 65 degrees Celsius with the highest temperatures occurring at the thruster.

C. Payload – Magnetometer

During its journey and at its final destination in the Van Allen belt, CLIMB performs magnetic field measurements. For this purpose a deployable magnetometer boom is attached to the side of the spacecraft. The 25 centimetre long boom features analogue magnetic sensors at the tip and halfway to the tip. Close to the magnetic field sensors, temperature sensors are placed to measure the temperature and also to estimate thermal drift of the magnetic field sensors.

D. Tests & Verifications

A series of in-house ground tests are performed. The available equipment includes a solar simulator, a Helmholtz coil, and a thermal vacuum chamber. Vibration tests are procured at FOTEC (Forschungs- und Technologietransfer GmbH), the scientific R&D (Research & Development) company owned by the University of Applied Sciences Wiener Neustadt.

Presently the CLIMB team focuses on the finalization of the satellite configuration. Firstly, for the solar arrays the preliminary design phase has been recently completed and mechanical (vibration) tests for the 2U-configuration of the solar arrays have been carried out. Next step is to test the 3U-configuration. Furthermore, more detailed numerical and experimental work is done with regard to the thermal design of CLIMB. These points are under current consideration and efforts are made to allow a launch date in early 2021.

V. CONCLUSION

The fulfilment of the scientific goal - i.e. obtaining measurement data of the space environment in the Van Allen belts - first requires the fulfilment of a technological goal: actively changing the orbit of the spacecraft. Orbital

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manoeuvres of the intended extent come with the well-known challenges of high specific impulse or a high propellant mass fraction. Achieving either of these on a CubeSat platform poses even greater difficulty. In that sense, CLIMB is pushing the boundaries of the state-of-the-art in nano-satellite technologies.

Frequent design iterations have led to a 3U design that can accommodate even the larger and heavier subsystems like the MAI-400 ADCS and the IFM Nano propulsion system. Deployable solar arrays increase the irradiated area nearly fivefold in order to harvest enough power to supply the highly efficient EP system.

The CLIMB team has so far investigated various options for the configuration, achieved a detailed design, and specified all major subsystems. Several open points in the design still exist but will be tackled in the upcoming months.

Acknowledgment

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Inertial Attitude Verification for ADCS Test Beds by Single Camera Image Processing

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***Abstract*—Test beds for attitude determination and control systems (ADCS) are an essential tool during the development and qualification phase of satellites which are often tested under simulated mission conditions. One major challenge is to verify a complete ADCS with its sensors without introducing noise to these sensors with testing equipment. Active sensors might interfere with magnetic field sensors, sun sensors or the optical instruments of the satellite.**

This paper introduces a cost-effective approach which determines a satellite's inertial attitude inside a testbed by only using images from a single or multiple commercial cameras. The software utilizes so-called ArUco markers which need to be physically affixed to the satellite and testbed itself. The attitude estimation can then be done with help of a software package developed by the authors. This software utilizes the open-source ArUco software library for detecting the markers, their position and orientation in the camera coordinate frame. Since it only uses images to do so, there is no interference with sensors or instruments of the satellite.

Keywords*—*ADCS, testbeds, satellite qualification, ROS, image processing, attitude determination, open-source, space robotics

I. Introduction

ArUco markers are synthetic two-dimensional markers that consist of a black border and a black and white pattern which is unique for every marker so they can be distinguished. The ArUco library [1][2][3] provides functions to generate markers to the user's specifications including border length, marker dictionary and marker ID. The dictionary defines the size of the pattern, i.e. the number of black and white squares, and the total numbers of IDs.

In addition to markers, there are also so called ArUco boards which are a set of prearranged markers which act as a single marker. The markers can be arranged in any 2D or 3D layout. Since the relative position between the markers are already known, it is possible to use all markers to estimate the pose of the board. This increases the accuracy of the estimation. Additionally, not all markers need to be visible to provide a pose estimation. If at least one marker is not obscured, an estimation can still be performed.

II. Package Features

The purpose of the developed package, *aruco_analyzer,* is to simplify the usage of the ArUco library and to add new features. For example, it allows to average successive estimations to mitigate estimation errors. The package can be configured using a configuration file in YAML format. In this configuration file, amongst other things, it is possible to specify which markers and boards the package is supposed to detect. Furthermore, the software allows to differentiate between space-fixed (stationary) and body-fixed (dynamic) markers.

Additionally, a wrapper for the Robotic Operating System (ROS) was developed. It subscribes to camera streams which can also be configured in the configuration file. The processed detections are published as images with the detected markers drawn into it and the pose estimations as ROS transformations[1].

III. Performance Evaluation

To evaluate the performance of the pose estimation, several tests were performed which can be divided into attitude estimation tests and position estimation tests. The goal of these tests was to find the impact of different factors on the estimation quality. These factors are mainly:

1. Kind of markers and boards being used,
2. Angle and distance of the camera to the markers.

All tests were performed with an off-the-shelf Logitech C920 USB[2] webcam at a resolution of 1080p and 30 frames per second. For the attitude estimation tests a script was implemented that performed the tests automatically using a rotary table for adjusting the codes' attitude.

During the initial research, the paper "Accuracy analysis of marker-based 3D visual localization" [4] was found which also dealt with pose estimations. They found out that at optimal conditions at 5m, the angular error was about 0.01° and the radial error about 8cm. At a certain distance, the errors increased exponentially, caused by the markers not being

1 docs.ros.org/kinetic/api/geometry_msgs/html/msg/TransformStamped.html
2 logitech.com/en-gb/product/hd-pro-webcam-c920

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detected correctly. However, judging by the paper, all tests were conducted in a simulated environment.

A. Attitude Estimation Evaluation

The accuracy of the attitude estimation is especially important for the application as a verification tool for attitude determination and control systems (ADCS) of satellites.

In the tests, a marker was placed on a rotary table with the camera placed at different distances above the table. The marker was rotated using the table at angles between 0° and 360°.

Table I shows some of the results of the attitude estimation test with different marker types and camera distances. In this test, the camera was always directly above the markers. The single marker performed significantly worse than all boards with a higher average and maximum error. At each distance, there is an optimal board type. In general, a board with more markers performs better. However, if the individual markers on the board get too small, the board is not detected reliably anymore at which point the attitude estimation deteriorates significantly. In the best case, we achieved an accuracy of less than less than 0.1°.

TABLE I. ATTITUDE ESTIMATION WITH DIFFERENT MARKER TYPES

Board type	Distance in cm	Error averaged over all angles in °		
		Average	Standard Deviation	Maximum
Single	56	-0.510	1.398	4.327
2x2		0.069	0.454	1.571
7x7		0.019	0.078	0.338
7x7	35	-0.003	0.054	0.226
10x10		0.000	0.029	0.066
15x15		-0.026	0.062	0.228

Table II shows some of the results of the attitude estimation test at different camera angles and a constant camera distance of 30cm. A camera angle of 90° means that the camera is directly above the marker. An angle shallower than 20° was not tested, as the markers were not detected reliably anymore. In the test, a 4x4 board with an edge length of 10cm was used. At the extreme cases of almost 90° and 20°, the accuracy is up to 5 times worse than at cases in between. The best result was delivered at 54°.

TABLE II. ATTITUDE ESTIMATION AT DIFFERENT CAMERA ANGLES

Camera angle in °	Error averaged over all angles in °		
	Average	Standard Deviation	Maximum
20.130	0.002	0.064	0.218
32.259	0.000	0.038	0.135
54.851	0.001	0.027	0.079
75.633	0.006	0.029	0.105
89.686	0.059	0.106	0.588

B. Position Estimation Evaluation

The position estimation is not as important as the attitude estimation for ADCS verification. However, applications such as the identification of landmarks for robotic navigation, it is crucial.

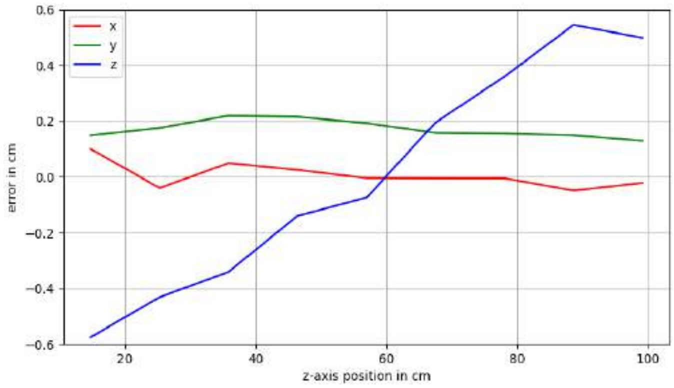

Fig. 1. Position estimation accuracy in all three axes. The camera was pointed directly at the marker. The z-axis can also be interpreted as the distance of the camera to the marker.

In this test, we investigated the accuracy of the position estimation by placing an ArUco board at different positions on a grid placed on the floor. This allowed to verify accuracy on the x- and z-axis, the x-axis being the horizontal position and the z-axis being the distance from the camera. The used ArUco board had an edge length of 10cm with 4x4 markers on it.

Fig. 1. shows the accuracy error of the position estimation dependent on the distance of the marker. The error in the x- and y-axis is relatively stable with a maximum error of around 0.1 and 0.2, respectively. The error along the z-axis increases with an increasing distance. This error follows a linear function which can be used to correct the position.

IV. CONCLUSION

We have shown that the ArUco library can be a useful tool for space-related projects. They can be utilized for the qualification of the attitude control system of a satellite to provide a simple and cost-effective method to verify the system's output. With its precision of less than 0.1°, it should deliver sufficiently accurate results.

For space rover projects or robotic projects in general, the ArUco markers can be used to mark important landmarks or objects which can be interacted with, like buttons or switches. Furthermore, it could be utilized to verify the output object recognition software based on another approach such as machine learning. The position estimation accuracy is around 0.2cm at distances from several centimeters to around 2m. However, to reach these levels of accuracy, the software must be properly calibrated beforehand.

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In-situ Observation of Ionospheric Plasma Aboard ESEO

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***Abstract*—This paper presents the expected scientific results of the Langmuir Probe Experiment (LMP) aboard the European Student Earth Orbiter (ESEO). LMP is an instrument designed to study the plasma environment in Earth's ionosphere. The instrument was developed by the Laboratory of Space Technology at Budapest University of Technology and Economics and Geodetic and Geophysical Institute of the Hungarian Academy of Sciences.**

***Keywords*—ESEO, micro-satellite, Earth observation, Langmuir probe, plasma, ionosphere**

I. About ESEO

The official description of the mission is as follows:

'ESEO is an ESA micro-satellite project with an educational objective: for the participating university students to acquire hands-on experience of a real space project, in order to prepare a well-qualified technical workforce for the European space sector. This was achieved by offering the students the opportunity to develop the payload (scientific instruments or technology demonstration experiments), key satellite subsystems and the ground segment (ground stations and Mission Control) to the mission, under the coordination of ESA and SITAEL, the Industrial Prime Contractor, responsible for the satellite platform, system integration and testing, and the technical coordination of the student teams. Run by the ESA Education Office, ESEO is part of ESA Academy's Hands-on Space Programme. Ten Universities from eight ESA Member States (Estonia, Germany, Hungary, Italy, Netherlands, Poland, Spain, UK) have participated in ESEO, with more than 600 university students involved in the project since its inception. The ESEO mission will validate in-orbit the SITAEL S-50 platform (50 kg including the payload), the smallest within the SITAEL products portfolio, and hence it represents a crucial milestone of the intensive hard work in designing, developing and manufacturing innovative multi-purpose small satellites platforms.' Our Laboratory developed the Langmuir Probe Experiment (LMP) and the Power Distribution Unit (PDU) of the satellite, a rendering of the satellite is shown on Fig. 1.

'ESEO was launched aboard the Spaceflight's SSO-A: SmallSat Express dedicated rideshare mission on a SpaceX Falcon 9 launcher from the Vandenberg Air Force Base in California, (US)' in December of 2018. ESEO is situated in a Sun-synchronous orbit with a perigee of 578.2 km and an apogee of 597.6 km. The mission entered commissioning phase in March of 2019, preliminary activation of payloads was originally scheduled for the late spring or summer of the same year. However, payload activation has been put on hold since the occurrence of a communication malfunction in April. The planned nominal operational period of the satellite is six months, of which LMP will be active for one month, with the possibility of further extending it for another year [1].

II. Effects of Solar Activity on the Ionosphere

The objective of LMP is to study the plasma environment. The altitude of ESEO places it within the F-layer of the ionosphere. The ionosphere is a region of the Earth's atmosphere, where particles of atmospheric gas ionized by solar radiation form a plasma layer. The ionosphere extends from approximately 50 km to 1000 km above sea level and can be divided into layers based on electron concentration. Ionization occurs in all parts of the atmosphere that receive sunlight, but a long-term plasma layer can only form at higher altitudes, where the rate of recombination is lower due to low air pressure. The ionized layers reflect the radio waves, thus enabling long distance radio communication.

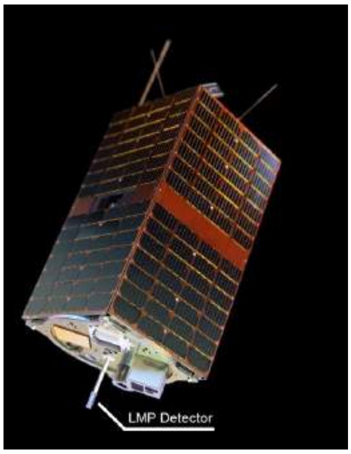

Fig. 1. The ESEO Spaceraft, credit: ESA

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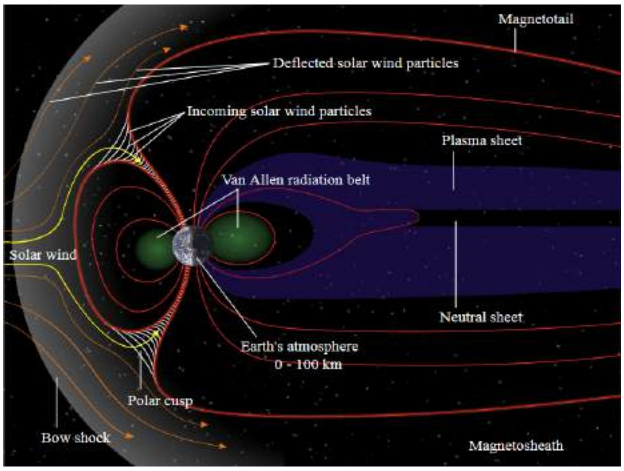

Fig. 2. Magnetosphere of the Earth, credit: William Crochot http://science.nasa.gov/newhome/headlines/guntersville98/images/mag_sketch_633.jpg

The ionosphere can be segmented into different layers depending on free electron density. The lowest layer is the D layer, above that are the E and F layers. In daylight the F layer breaks into the lower F1 and the upper F2 layers. At night the lower layer is neutralized through recombination. To have a better understanding of the phenomena happening in this region, we need to examine, how the Sun affects the Earth's ionosphere and magnetosphere.

The activities of the Sun can be categorized into two different groups: periodic and non-periodic activities. Periodic activities can have a period of 11 years and 27 days, 11 years is half of the period of the polarity shift of the Sun's magnetosphere, and 27 days is the length of the Sun's rotational period. Non-periodic or stochastic activities are for example the solar flares and the coronal mass ejections (CMEs). During these events low density plasma containing high-speed electrons and ions is ejected into space. These particles form the solar wind. The solar wind interacts with the Earth's magnetosphere and particles of the solar wind are added to magnetospheric plasma. The Earth's magnetic field is the field of a magnetic dipole deformed by the solar wind. The solar wind blows the magnetic field from the side facing the Sun to the opposite side of the planet, creating the magnetotail. The solar wind creates a bow shock on the side facing the Sun. At the pole cap the field lines of the Earth's magnetic field are open, this area is surrounded by the polar light belt, as shown on Fig. 2. In the ionosphere, where ESEO orbits, the Earth's magnetic field can be considered a dipole.

The solar wind has another effect on the force lines, called merging. This event occurs, when the field lines of the interplanetary magnetic field have a component in the southern direction. The magnetic field lines carried by the solar wind merge with the outer geomagnetic field lines on the side close to the Sun. During the merging the solar wind plasma is absorbed into the magnetosphere and it is directed towards the axis of the magnetotail by the electromagnetic field, building up a plasma layer in the plane of the axis of the magnetotail. Some particles of this plasma layer are accelerated into the Aurora Oval. Upon collision, they transfer energy into the local plasma, ultimately causing a temperature increase, which causes an upward drift on high and mid-high latitudes. As a result, the density of the O_2 and N_2 molecules will be higher compared to the density of the O atoms, and because of this the speed of recombination will be high enough to decrease the electron density.

CMEs and solar flares also cause disturbances in the geomagnetic field and the ionosphere. During negative ionospheric storms appear there is a large decrease in electron density. These storms are typical in mid and high latitudes. During positive ionospheric storms electron density increases, they can occur on lower latitudes. The so-called ionospheric troughs are also worth mentioning. They can appear in the lower part of the F-layer but can be detected in the orbit of ESEO in case of intense geomagnetic storms. The typical sign of these phenomena is decreased electron density [2].

III. Scientific objectives

Both spatial and temporal anomalies can be observed in electron density. At the orbit of ESEO there are three major areas of interest: the geomagnetic equatorial plane, the South-Atlantic Anomaly and geomagnetic latitudes under and over the polar light belt.

At the geomagnetic equator the product of $\mathbf{E}\times\mathbf{B}$ points upwards due to the horizontal component of the geomagnetic field. This causes an upward drift in ion density, which creates 'plasma bubbles' with decreased electron density along the geomagnetic field lines. These plasma bubbles can have a size of hundreds of kilometers and can disturb radio communication, which effect aircraft navigational systems.

The axis of the geomagnetic field is tilted away from the rotational axis of the Earth, and because of this the inner Van-Allen belt dips lower into the atmosphere. This causes an anomaly in the electron density over the South Atlantic, here the flow of particles has a much higher flux, which can damage electronic equipment. Satellites in low-Earth orbit passing over this area need to be prepared for this type of hazard and because of this it is recommended to monitor this anomaly.

At the polar light belt the electron density has a maximum compared to the lower and higher geomagnetic latitudes. Therefore, from the analysis of the electron density over this area the location and the latitude of the polar light belt could be observed, which is possible due to the polar orbit of ESEO.

Some notable temporal anomalies are the daily anomaly and the winter anomaly. The daily anomaly is, when the maximum of electron density is delayed from noon to afternoon. To properly observe this anomaly the experiment should take measurements at the same place at different times, but this is not possible due to the sun-synchronous orbit of ESEO, however, comparing measurements taken at close longitudes might still be useful in studying this anomaly. Another temporal anomaly is the winter anomaly: during the winter of the northern hemisphere the measured electron density here is higher, than at the southern hemisphere during the winter of the southern hemisphere. The operation time of LMP will be only one month, and because of this we cannot observe this anomaly, however, if the mission is extended for a further year there is a possibility.

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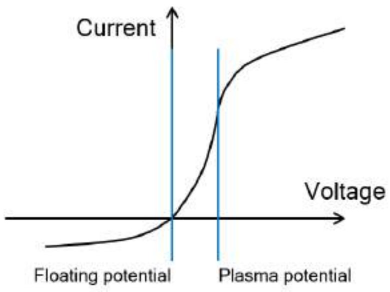

Fig. 3. UI curve of a Langmuir probe

IV. THE LANGMUIR PROBE PRINCIPLE

A. Introduction

A Langmuir probe is a device used to determine the physical characteristics of a plasma using in-situ measurements. It works by immersing two conductors in the plasma, applying an excitation voltage between them and measuring the current flowing through one or both of the conductors. If the surface area of one of the conductors is significantly larger than that of the other the configuration is referred to as 'single pole', if not it is a 'double pole'. In single pole configurations the larger conductor can be the container wall in case of a plasma container or the chassis of a spacecraft. The electron density, electron temperature and ion temperature of the plasma can be determined by analyzing the probe current. By varying the excitation voltage, the current of the probe will also vary according to the UI curve, which is characteristic of the plasma. The shape of the curve is highly dependent on the three plasma parameters mentioned above, the typical shape is shown on Fig. 3. A measurement using a Langmuir probe consists of recording the UI curve and using curve fitting to determine the value of the plasma parameters.

B. Understanding the UI curve

The current flowing through the Langmuir probe is provided by the ions and electrons of the plasma. The probe current can be expressed as a sum of its two constituent currents the electron and ion current. The shape of the two currents is similar, electron current is positive and ion current is negative. The magnitude of the electron current is significantly higher than that of the ion current, due to the lower mass and consequently higher mobility of electrons. The plasma potential (U_P) splits the voltage range into two regions. The plasma potential is the potential of the undisturbed plasma (also called bulk plasma), which is considered to be uniform in the vicinity of the probe. If the probe potential is higher than the plasma potential, the probe attracts electrons and repels ions. Similarly, at potentials lower than the plasma potential the probe attracts ions and repels electrons. Therefore, the ion and electron currents can be further subdivided into repelling and attracting (also called saturation) regions as shown on Fig. 4 [3] [4].

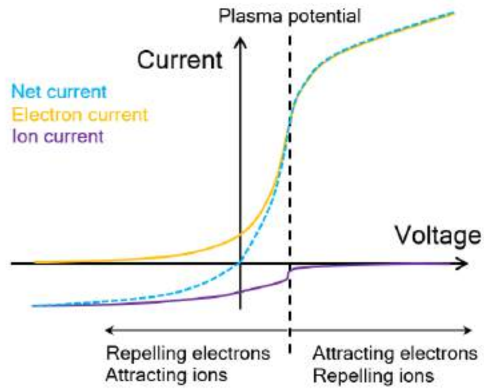

Fig. 4. Langmuir probe current decomposition

The magnitude of both the electron and ion current in their respective repelling regions is an exponential function of ratio of the probe voltage and the electron/ion temperature, as shown in (1). Where e is the elementary charge, k is the Boltzmann constant and n is the ion or electron density, U_P is the plasma potential and T is the appropriate temperature.

$$|I| \sim n \cdot \exp(e|U - U_P|/kT) \quad (1)$$

This formula shows that the further the probe voltage is from the plasma potential the more repulsion the particles have to overcome and thus their current contribution decreases. Only those particles can reach the surface of the probe whose kinetic energy is greater than the energy of the electric field of the probe. The velocity of the particles follows a Maxwell-Boltzmann distribution, precise derivation of the formula is given by Shun'ko in [2]. In the saturation region all particles can reach the probe regardless of kinetic energy, however, the probe current still increases with the voltage, because the current collecting region around the probe (the sheath) grows with increasing voltage. The saturation current is proportional to the square root of the probe voltage [3] [5].

$$|I| \sim n \cdot \sqrt{|U - U_P|} \quad (2)$$

The total probe current is the sum of the ion and electron currents. In the saturation regions the probe current approximately equals the respective saturation current, and thus it is possible to use these sections of the UI curve to estimate the electron and ion densities. Note, that at the so-called 'floating potential' the current is zero, this potential is in the range of ion attraction and electron repulsion. Any conductor left undisturbed in the plasma will be charged to floating potential after a sufficiently long time. Floating potential is always lower than the plasma potential. Because of the greater mobility of electrons, a slight negative charge is needed to decrease the electron current, so the currents are of equal magnitude. Since the spacecraft chassis is at floating potential, the UI curve measured by an on-board Langmuir probe will have its origin at the floating potential and the plasma potential will appear as positive.

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The region between the floating and plasma potentials is referred to as the retardation region. In the upper part of this region the electron current is dominant, the net current of the probe approximately equals the electron current and the electron temperature can be obtained. The ion current cannot be determined by this measurement, because in the ion repelling region the ion current is overshadowed by the electron saturation current.

C. *Additional considerations*

Besides the basic principle of operation, there are also some other phenomena present with Langmuir probes. The most important may be the Debye length. When a conductor is immersed in plasma the electric potential in the surrounding plasma shows an exponential decay towards the plasma potential, the Debye length is the characteristic length of this exponential decay. It is important to place the probe sufficiently far away from the satellite, so it 'sees' the undisturbed plasma. For this purpose, one Debye length away from the satellite would be enough, however, the probe has its own disturbing field, thus a distance of two Debye lengths between the probe and the satellite is a safe choice [2].

Another point to consider is the average velocity of plasma particles. In deriving the current of the Langmuir probe, we relied upon the assumption that the population of incoming particles are symmetric in velocity space, meaning there is not a single distinguished direction where the particles are coming from, rather they arrive randomly from all directions. The velocity of the electrons and ions does not reach a common equilibrium, instead they both reach a state of equilibrium amongst themselves, thus the plasma can be characterized by two velocity distributions, one for ions and one for electrons. Because of the lower mass the average velocity of electrons is much higher than that of ions, even at minimum electron temperature the average velocity is above 100 000 m/s, which is much higher than the average velocity of the spacecraft (approximately 7500 m/s). However, the average ion velocity varies between 2800 m/s and 8500 m/s, which is comparable to the velocity of the spacecraft, which can influence measurement results.

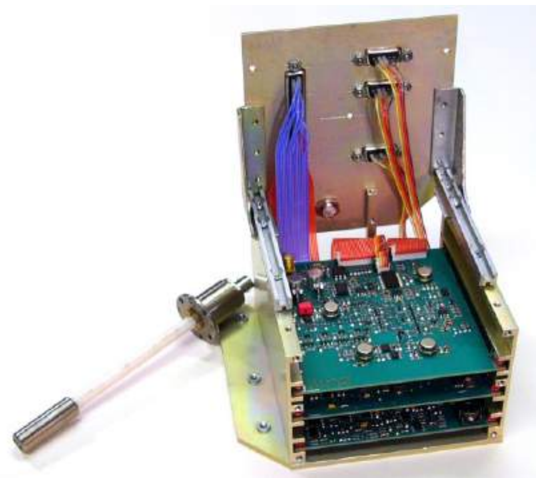

Fig. 5. The LMP instrument

V. Description of the LMP instrument

A. *Overview*

As we have seen, a Langmuir probe needs to record the UI curve for the plasma characteristics to be assessed. The on-board instrument needs to provide the excitation voltage, measure the current, and store the digitized results for later transmission to ground, where the analysis takes place. The instrument also needs to perform measurements automatically to achieve the desired spatial resolution. Fulfilling all these requirements necessitates a complex electronic support equipment alongside the probe. The probe and its mechanical support, collectively referred to as the Langmuir Detector (LDE) is located on the bottom of the satellite, which is normally nadir-pointing. The electronic box, called the Langmuir Control Box (LCB) is housed within the satellite and it is connected to the LDE via triaxial cable to minimize noise. The LCB contains three electronic boards: the amplifier, the on-board data handler (OBDH) and the power supply. The amplifier is responsible for producing the excitation voltage and converting the probe current into a voltage signal able to be digitized. The OBDH performs analog/digital conversions, controls the probe voltage, stores and forwards data towards the transmitter, oversees the timing of the measurements and the operational modes.

B. *Detector design*

LMP uses a single, cylindrical electrode 39 mm in length and 13 mm in diameter. The electrode is made of titanium to minimize the current due to photoemission [5]. It is fitted on top of a 90 mm long ceramic insulator rod. The length of the insulator is over twice the length of the maximal Debye length of 40 mm. An image of the detector is shown on Fig 5. The surface area of the electrode is approximately 17 cm^2. The surface area is directly proportional to the magnitude of the probe current; therefore, a large enough surface area is necessary to achieve a good signal-to-noise ratio in the current. However, the surface of the satellite needs to be significantly larger than the surface of the probe for the spacecraft potential to remain unaffected by the biasing of the probe, as explained in [5]. Mass constraints and mechanical dimensions also present an upper limit for the size of the probe.

C. *Amplifier design*

The amplifier needs to accurately set the probe voltage and produce a voltage signal proportional to the probe current. The probe bias voltage can be set anywhere within the range of ±8.7 V with an accuracy of 17 mV. Because the probe current has a large dynamic range (it can range from picoamperes to milliamperes) the current-to-voltage amplifier uses compensating current technique with a variable feedback network to implement multiple ranges. The amplifier is capable of automatic range control, but the OBDH can overtake this function if necessary. The amplifier also has a built-in test network which can simulate different levels of probe current, it is used for precise in-flight monitoring of the gain and offset of the amplifier. A simplified block scheme of the amplifier is shown on Fig 6.

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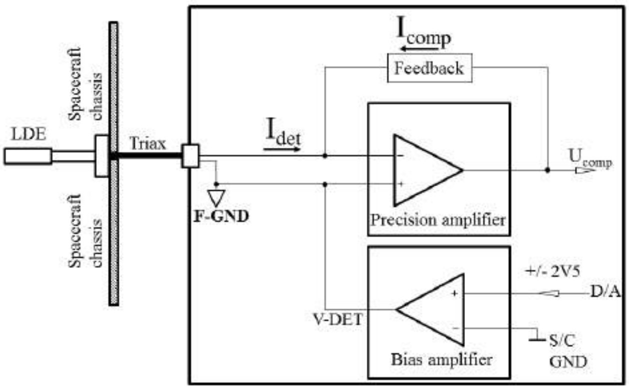

Fig. 6. Simplified block scheme of the amplifier

D. Operational modes

To map the entire UI curve the probe bias voltage is swept across the selected voltage range while both the probe current and voltage are recorded. The voltage sweep is performed in 100 steps, the default sweep time is 300 ms, the probe spends 3 ms at each voltage level, which is sufficient time for the step-response of the amplifier-probe system to settle. Considering that the average velocity of the spacecraft is approximately 7500 m/s one UI curve will be recorded over a distance of 2.25 km. LMP alternates between four different sweep patterns shown on Fig. 7. Two of the sweeps have a section with lower voltage difference between the step in the middle, which allows for a more detailed sampling of the retardation region, where the slope is the steepest. The sweep can be performed either with increasing or decreasing voltage.

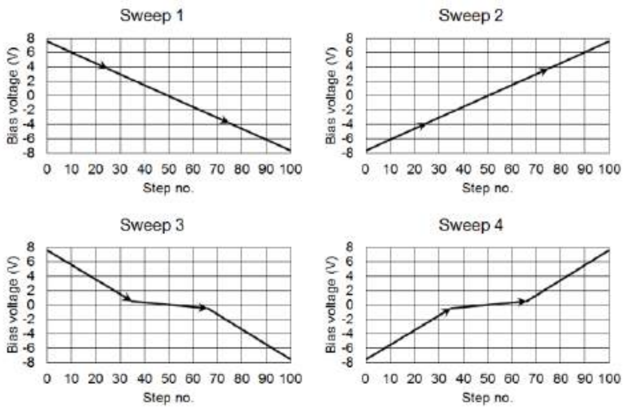

Fig. 7. Bias voltage sweep profiles

LMP can gather data in three operational modes: nominal, adaptive and self-test operation, other operational modes, such as fail-safe are not discussed here. In nominal mode a sweep is performed every second, which means that a measurement is performed every 7.75 km or 0.0064° assuming a circular orbit. In adaptive mode a new UI curve is recorded whenever there is a larger change in electron density, which is proportional to the electron saturation current. This operational mode can generate large amounts of data and a quick consumption of memory. Entering adaptive mode can be triggered via telecommand. Sweep time, measurement frequency, voltage range and voltage step can also be configured by telecommand.

VI. Conclusion

In this paper the LMP experiment was presented. LMP is an experiment designed to study the plasma environment of the upper ionosphere using the Langmuir probe principle. The measurement method was explained, and a brief description of the instrumentation was given. LMP will be able to determine the ion and electron density and electron temperature of the plasma. The scientific goal of the mission is to study the plasma anomalies, which will help to better understand the effects of the solar activity on the geomagnetic field. Currently the ESEO mission is in its commissioning phase, in-orbit verification of the payloads is yet to be performed.

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AIM (Artery In Microgravity): An ICE Cubes Mission by University Students

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***Abstract*—**The ICE Cubes Facility is a capable experiment platform on board the Columbus Module of the International Space Station that offers flexibility to host many different experiments. The ICE Cubes Facility is suited for any scientific research and technological demonstrator that requires the study of the effects of microgravity and radiation exposure in a pressurised volume. The ICE Cube Service is also open to different schooling levels (primary, secondary, universities) and to different STEAM curricula and offers University students (Master and PhD) the opportunity to design, develop, test and operate a real experiment for the ISS under the supervision of experts from the ICE Cube Service.

The Artery In Microgravity (AIM) project is a 2U ICE Cubes experiment cube and the first experiment to be selected for the Orbit Your Thesis! programme of ESA Academy. The cube is expected to be launched on SpaceX-20 in early 2020. The project is being developed by an international group of students from ISAE-Supaero and Politecnico di Torino.

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The experiment will investigate coronary heart disease, the most common form of cardiovascular disease and the cause of approximately 9 million deaths every year. In view of the very long duration missions to come, such diseases may also affect healthy astronauts in space. The AIM cube is a test-bench for investigating haemodynamics in microgravity and will study the effects of microgravity on blood flow in the coronary artery with and without an implanted coronary stent and the impact of augmented radiation levels on metallic ion release from coronary stents.

The experimental setup consists of a closed hydraulic loop containing two models of a coronary artery in series. An electric pump and reservoir will control the flow of a blood-mimicking fluid through the system. One model of the coronary artery will contain a coronary stent. The pressure of the fluid will be studied along its path using a series of pressure sensors and a camera will visualise the flow. Ground tests will be conducted concurrently in order to perform a comparison between the on-ground behaviour and the behaviour in microgravity.

The paper will showcase the design and development of the AIM experiment cube, the results of testing and the educational applications of the ICE Cubes Facility. The full data and results will be available after the completion of the mission which is expected to be between March and June 2020.

Keywords—ICE Cube Service, STEAM, Education, Haemodynamics, Microgravity

I. INTRODUCTION

The AIM (Artery in Microgravity) project is a 2U experiment cube that can be housed within the ICE Cubes facility on board the Columbus module of the International Space Station.

The cube is being developed by an international and interdisciplinary group of students from ISAE-SUPAERO in Toulouse, France and Politecnico di Torino, Turin, Italy. The project is the first to be selected for the 'Orbit Your Thesis!' Programme of ESA Academy.

The 'Orbit Your Thesis!' programme is the latest student opportunity of ESA Academy that sponsors and supports a group of students to develop an experiment that will be launched to the International Space Station. The other programmes of ESA Education include 'Fly Your Thesis!', 'Spin Your Thesis!' ,'Spin Your Thesis! Human Edition', 'Drop Your Thesis', and 'Fly Your Satellite' in which students develop an experiment for a Novespace parabolic flight, the Large Diameter Centrifuge in ESTEC, Short Arm Human Centrifuge in Cologne, the ZARM Drop Tower in Bremen and launch into space respectively.

The AIM project was selected for the Orbit Your Thesis! programme in October 2018. At the time of selection, the team composed of 7 Master's students of Aerospace Engineering from ISAE-SUPAERO in Toulouse, France. Since the project began, it has expanded to include a PhD student and a master's student of Biomedical Engineering from Politecnico di Torino and 2 more students of Aerospace Engineering from ISAE-SUPAERO who are taking over leadership of the project as of September 2019. The team was split into 3 main sub-groups based on expertise: scientific team, mechanical team and electronics team. Olivia Drayson and Nicolò Bernardini acted as team leaders.

The experiment studies the impact of microgravity on haemodynamics within a stenotic coronary artery and a stented coronary artery and the effect of heightened radiation levels on coronary stents.

II. ICE CUBES SERVICE

A. ICE Cubes

Research in microgravity allows for a wide range of science disciplines and the International Space Station (ISS) is one of the most powerful science laboratories available to the science community to conduct such research. Thanks to a partnership between the European Space Agency (ESA) and Space Applications Services (SAS), it became recently easier to fly experiments on-board the ISS.

The International Commercial Experiment Cubes Service, or ICE Cubes Service, provides a fast and affordable access to the ISS for scientific research, technological demonstrators and for educational purposes that require microgravity conditions and radiation exposure in a pressurised volume. The ICE Cubes Service makes use of the ICE Cubes Facility, a sliding platform permanently installed on-board the ISS that accommodates "plug-and-play" Experiment Cubes and that hosts the functional interfaces to the ISS infrastructure.

Space is becoming an additional room for terrestrial laboratories to increase knowledge and develop businesses thanks to new simplified approaches. Commercial services like ICE Cubes offer the possibility to any organisation or customer to perform their activity in LEO and on the Moon at an accessible cost and at well-predefined conditions. The ICE Cubes Service, by involving students in this inspirational journey, contributes to the next generation of scientists and engineers meant to create terrestrial benefits making use of space assets.

In that respect, the ICE Cubes Service is open to different schooling levels (primary, secondary, universities) and to different STEAM curricula and offers several Educational Packages ranging from concept development up to designing, developing, testing and operating an entire cube. As an example, this paper will present the first student Experiment Cube to be selected for the Orbit Your Thesis! programme of ESA Academy.

III. ORGANISATION OF THE AIM PROJECT

B. Team Structure

After conception of a preliminary experiment design, the priority of the project leaders was to build a team for the project. Originally the project team consisted of only master's students from ISAE-SUPAERO specialising in different majors of Aerospace Engineering. The Mechanical team was chosen to consist of students specialising in Aerospace Structures. The

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Electronics team was chosen to consist of students specialising in Control and Space Systems. The Scientific team was chosen to consist of students specialising in Space Systems. In order to provide medical expertise to the team, two Biomedical Engineering students were recruited to the scientific team from Politecnico di Torino.

Since the project lasted longer than the master's degrees of the technical branch of the team, two incoming students were recruited to take over leadership. They were chosen to be students specialising in Space Systems and were trained in order to lead one of the two branches of the technical team.

C. *Project Development Timeline*

An ICE Cube Mission typically takes 12 months from contract signature to launch. The current anticipated launch date of the AIM cube is 3rd March 2020 on board the SpaceX Falcon 9 launcher. When planning the timeline of the project development, the phase definition nomenclature used by NASA and other space agencies was adopted [1].

The project was accepted into and thereby commenced the OYT programme in October 2018. At this stage a preliminary concept had been approved and therefore Phase A was complete. Phase B - Preliminary Design and Technology Completion - started upon recruitment of the Biomedical Engineering students and was completed in February 2019 upon approval from ESA of the Experiment Requirements Document and Preliminary Experiment Design. Phase C - Final Design and Fabrication - is almost complete, planned to finish in September 2019. Phase D - System Assembly, Integration and Test, and Launch - was started in July 2019 and is planned to be completed upon launch in March 2020.

IV. DESIGN OF THE AIM EXPERIMENT

D. *Scientific Context*

Cardiovascular disease (CVD) is the leading cause of death in the world [2]. While cardiovascular disease covers many different pathologies, the one with the highest death rate is coronary artery disease (CAD). CAD occurs due to the presence of atherosclerosis in the arteries that feed the heart. This impedes blood flow and can result in the obstruction of the vessels, stimulating a myocardial infarction (heart attack).

Space exploration increases the risk of CVD through many factors including radiation, confinement and reduced gravitational loading [3]. Therefore, both microgravity and radiation in the space environment are potential triggers for deterioration of the cardiovascular system during manned space exploration.

Atherosclerotic lesions (atheromata) are asymmetric focal thickening of the innermost layer of the artery (the intima) [4]. The localisation of atherosclerosis in the coronary arteries may be governed by local haemodynamic features. Haemodynamic shear stress has been shown to be an important factor in the development of atherosclerosis at several important sites of the arterial system [5].

E. *Experimental Concept*

An experiment that investigates haemodynamics in coronary arteries was thus developed in order to investigate how the altered haemodynamics in microgravity may exacerbate or diminish atherosclerotic lesions in coronary arteries and thereby determine how the risk to astronauts of myocardial infarction is affected by space travel. In addition, the experiment makes use of the radiation environment on board the ISS to investigate if implantable devices such as coronary stents are at risk of re-stenosis due to the release of metallic ions stimulated by radiation exposure.

The experiment contains two models of a stenotic coronary artery constructed from clear silicone. One artery model contains an implanted coronary stent and a water and glycerol mixture will be pumped through the two models in series. A red dye will be injected afferent to the two models and a camera will visualise the flow whilst in orbit.

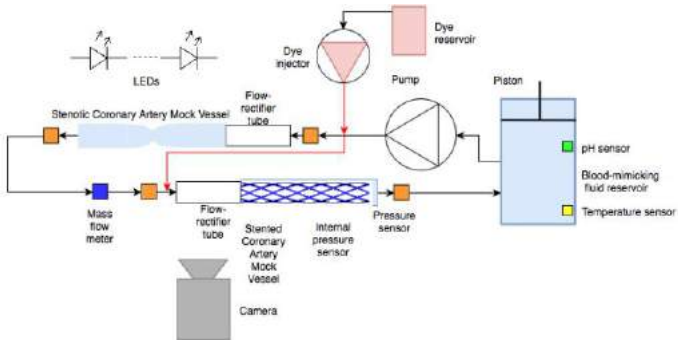

Fig. 1. Test bench for investigating coronary haemodynamics

V. DEVELOPMENT OF THE AIM CUBE

F. *Hydraulic Loop Construction*

The main part of the experiment is the hydraulic loop, consisting of the coronary artery models, the pumps, the dye reservoir, connecting tubing and check valves. This part of the experiment was constructed in Politecnico di Torino and will be combined with the remainder of the cube in ISAE-SUPAERO. A first version of the hydraulic loop has been built and tested by S. Gabetti and E. Torta in Politecnico di Torino capable of performing dye injection without leaks.

Most of the components are commercial off-the-shelf products with the exception of the stent and coronary vessels. The coronary arteries shall be 3D printed in silicone and the coronary stents were provided to the team by AlviMedica who are a sponsor of the project.

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G. Mechanical Construction

The major mechanical components for this project were the external structure of the cube and the reservoir, both of which needed to be built on the university premises (ISAE-SUPAERO) due to lack of commercial options.

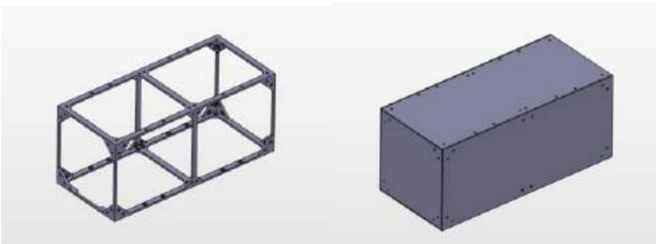

Fig. 2. (a) Internal frame and (b) external panels of ICE Cube external structure

The external structure was designed in order to meet the performance requirements of the ICE Cubes Service regarding launch load factors and random vibration [6]. The amount of material required for the internal frame was then minimised in order to maximise space available for the components within the cube, minimise mass and ease the assembly process. The structure is composed of an internal frame constructed from ABS and with threaded inserts to accommodate screws. Aluminium panels will be screwed onto the frame in order to close the cube. The corners of the cube will then be rounded off to prevent injury to astronauts.

As the ICE Cube is a new type of mission in space it is not possible to find references regarding many aspects of its design, including the structure. For this reason, the structure went through different modifications to finally have the present design. The complexity given by different elements (size restrictions, components dimensions, structural strength) is the main factor that lead to different designs for both internal components and the structure.

The second constructed component was the reservoir. Since the largest risk to the experiment would be a leak of fluid, the reservoir needed to contain a volume of fluid under pressure throughout the mission whilst preventing air from entering the loop. Trapped air bubbles could rupture the system and introduce leaks or affect results. A bubble trapper was considered to reduce the risk of trapped air in the system; however, it was disregarded due to a lack of commercial options that were suited to the flow rate of the experiment. A piston was chosen as the method of pressuring the reservoir without introducing gas.

Once a preliminary hydraulic loop was built, different reservoir sizes were tested with the pumps in order to determine the minimum volume required. It was found that 100ml was sufficient to absorb fluid momentum while leaving a suitable margin. Once the volume had been ascertained the design of the reservoir could be finalised.

Another issue that needed to be addressed when designing the reservoir was the method of sealing connections. In addition to the input and output connections a pH probe will be inserted into the reservoir and the piston itself should be sealed against water and air. The piston will contain two O-rings to separate the air from the fluid. A waterproof connector for the pH probe has been built and tested.

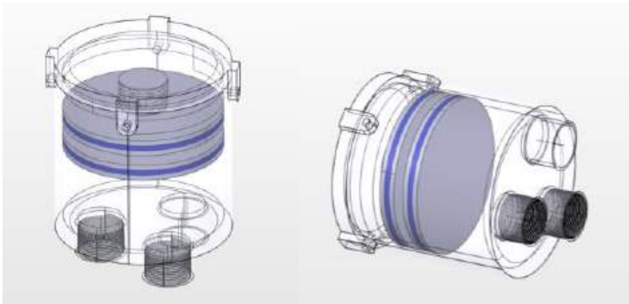

Fig. 3. CAD model of the current reservoir design

H. Electronics Construction

The electronics team has been working on the design of the architecture system to control the experiment so that it works autonomously. The primary requirements that affect the electronics are the power provided[1] and the available data downlink rate[2].

Following all the requirements, the motherboard, as well as all the devices (camera, pressure, temperature and pH sensors, pump and motor drivers) have been selected, in collaboration with the scientific team.

Firstly, the initialisation of the motherboard (Odroid C2) with an OS and all the packages necessaries was prepared, followed by the testing of the camera and every single device to finally define a main script to control the system. It has been decided that the pump will be running continuously during the 4 months, because switching it on and off over the course of the mission increases the risk of fluid leaks. Different flow rates will be imposed; therefore, the pump will be programmed to gradually increase and decrease its intensity using Pulse Width Modulation (PWM). When it does not take the measurements the flow rate will be set at the minimum. Each day measurements will be taken from each sensor; the camera will capture a short video when illuminated by the LEDs. Currently, the design of the code is being implemented and the physical circuit is being developed to find a good configuration that will fit perfectly inside the cube.

[1] A 12V line at 3A and a 5V line at 0.9A is accessible for each DB13W3 connector [6].

[2] up to 4Mbps

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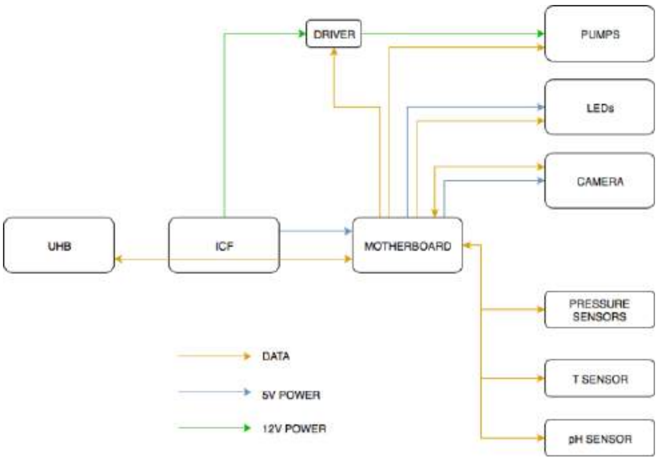

Fig. 4. Electronic block diagram[3]

VI. TEST RESULTS

For the external structure, the tests have been performed using FEM (Finite Element Method) on a commercial software. This allowed for computation of the first characteristic frequencies of the structure using the data shown in table 1 and the first 5 frequencies are in table 2. These results are only partial as the analysis has been done taking into consideration only the supporting structure and it does not take into account the effect of the other components. To have a definitive conclusion regarding the vibration study it is necessary to wait for the data from the physical tests.

TABLE I. MECHANICAL PROPERTIES OF EXTERNAL STRUCTURE

Component	***Density (kg/m³)***	***Volume (m³)***	***Mass (kg)***
Internal Structure	1060	4.51 E-05	0.0478
Panels	2700	1.41 E-05	0.0380

TABLE II. RESULTS OF FEM FREQUENCY ANALYSIS

Modal Analysis		
Mode	***Frequencies (Hz)***	***Max. Displacement (mm)***
1	93.686	1.393
2	129.61	1.217
3	130.77	1.194
4	144.21	1
5	190.8	1.166

VII. CONCLUSION

Whilst this project is still in progress, the design of the experiment and the choice of its components has been finalised. Construction of the first model is expected to be completed at the end of September 2019 after which a test campaign will be conducted. The test campaign will include random vibration tests, vacuum tests, EMC tests, DC magnetic tests, audible noise tests and an interface test with the ICE Cube Facility.

The primary goal of the AIM Cube is an educational opportunity for the university students involved. On top of the training week conducted with ESA Academy, the process has taught the students about the planning and execution of space missions, management of engineering teams and the application of engineering and scientific principles in a space context. For these reasons, the design and development of an ICE Cube mission is a highly recommended endeavour for any university student team for the educational benefits alone but can also provide access to a unique environment that can benefit university research and student projects alike.

ACKNOWLEDGMENT

We would like to thank the sponsors of this project for their support; ESA Education, Fondation ISAE-SUPAERO, AlviMedica and AIRBUS AGGUP. Special thanks to Space Applications Services, ISAE-SUPAERO and Politecnico di Torino.

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[3]UHB is the User Home Base and ICF is the ICE Cube Facility

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THE IMPLEMENTATION OF ASTRONOMY AS A TEACHING-LEARNING TOOL AT HIGH SCHOOL STUDENTS IN MANAUS

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***Abstract*—**Brazil is a country with low emphasis in astronomy education in the Public Educational System. At a very early age, students of the Public Education System have a very poorly introduction in science, the teachers are badly equipped to teach and the problems in our system lead to low qualified professionals and an aversion to science in general. Our work aimed to teach, encourage and inspire high school students that lived and studied at slums and low-income neighborhoods to put science in their lives through astronomy classes and also try to multiply the amount of people that can multiply that knowledge through the world.

We went to some schools that really needed support and started a weekly basis class with students that wanted to learn astronomy as they did not have that kind of class growing up. As the classes progressed, the students seemed more interested with the classes at school and more willing to learn what was being taught at school, and as a result they were more inclined to join our University and start learning more about Engineering, Astrophysics, Programing and more. We aim with this work to start a new era of Education in our country were science has a stronger focus in young students, and in the process, creating people that can help build a new, better and well-structured country.

Keywords—Atronomy, science, school, education, student

I. Introduction

For many high school students, physics is the worst nightmarish subject, full of equations to memorize and hard to solve questions. To the teacher is up the difficult task to unravel this science and bring it to the classroom, in a diversified and interesting way. Seeking to ease this problem, a Project was developed with the proposal of inserting activities involving Astronomy in high school, that because of its multidisciplinary character, is shown a useful tool to the teachers that intend to captivate and motivate their students.

Due to the Fact that Astronomy is not a discipline in the Brazilian school curriculum, we have to work with astronomy teaching informally [1], by introducing activities related to their subjects inside classes of other disciplines as a way to complement the proposed knowledge. So, the activities of this Project will be developed with First Year High School students.

II. Methodology

We believe that the Astronomy teaching must be presented side by side with the technological advancements incorporated with the scientific breakthroughs that are being discovered at the Research Centers [2]. Although, the knowledge produced at the Research Centers and Universities need to go through a didactic transposition that further the comprehension of the students. As the main method to the progress of the proposed activities, we used the Method of Didactic Transposition of Yves Chevallard [3].

By separating two classes, one canonic (which will receive traditional Physics classes) and a pilot one (that will receive an intervention), we are interested to see the effectiveness of the insertion of astronomy teaching as a motivating agent for teaching-learning of science for students in the first year of High School. For that, we take as a theoretical framework the subjects of Mechanics and Kinematics, and had been thought of in a sequence of 6 lessons divided into 2 main moments.

In the first moment we will propose a moment of conversation with the students in order to grasp their perceptions about Physics and its importance for the comprehension and development of Society. Then, through a lecture (using slides and projector, or, in their absence, putting together a line of ideas on the board) students will be introduced to some ideas about the origin of movements studying quick points on the history of astronomy. After that, we will start effectively the study of some movements like uniform rectilinear motion and uniformly variable movement. A time will also be reserved for the resolution of proposed exercises in the classroom.

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In a second moment, we will present Newton's laws of motion, those expositions will aid them to get used to physical phenomena in our planet and try to quantify the same. Aiming to provide a more playful moment, a practical activity on assembly and rocket launching made from recyclable material was proposed, thus bringing not only a moment of teacher-student interaction, but also an applicability of the contents studied in the second didactic moment.

Finally, the effectiveness of the activities was assessed by means of questionnaires, group activities and discourse analysis, where reports were collected during specific classes [4].

III. FINAL RESULTS

It was explained that the first didactic moment we would implement as a initial part of the cinematics content, and, after that, there would be a break in the implementation for the students to prepare with necessary subjects to continue with the implementation of the project. However, the teacher that was assigned to us missed a lot of classes he was supposed to give and it delayed our job that was supposed to be done in 4 weeks to 7 weeks.

In Mid-April the teachers from the State Network from Manaus declared a strike that prolonged to the end of May, delaying our job in more than one month, totalizing 12 weeks of delay in our application.

During some classes, a couple of students started to harass Celeste moaning at her and proclaiming some very disrespectful words, this made her feel unsafe at the facility and we took the issue to the Principal of the school, they searched for the students that did this and punished the appropriated way so that we could go back to work.

At the end of the activities, the student's engagement and their morale became evident. Some of them commented that they would like to follow some of the science careers in engineering, physics and other subjects. Due to their socioeconomic reality, these careers are, in their minds, something impossible and unreachable and the project was proven satisfactory in such scope.

IV. CONCLUSION

In the implementation process of this project, the students' desire to a differentiated and more comprehensive education. Even though it was not possible to apply of the proposal in its entirety at the school, students are still looking for us to ask when will be the next astronomy class and this is nothing but a yearning on the part of students to see a current and applicable science in their classroom [5] However, in this process, the active participation of the teacher as mediator is essential. this knowledge to create a mutual sharing environment, where science teaching is not only seen by its technical and scientific terms but also be recognized as part of human construction and its relations with the human social, cultural, economic and political context around us. [6]. Due to the socioeconomic reality of the students, our presence there was a decisive point in their lives, so that they can choose a career that suits them and give them and their families a better life.

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The Sheffield Space Initiative - Introduction, Motivation, and Impact Assessment

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***Abstract*—In the rapidly changing landscape of 'New Space' and 'disruptive innovation', the University of Sheffield has identified the need for bespoke and focused training for students wishing to enter the space industry. The Sheffield Space Initiative (SSI) is a group of student-led projects at the University of Sheffield. Its purpose is to provide highly motivated and passionate students with the opportunity to participate in space related projects and work within multidisciplinary teams to address real-world challenges in space engineering.**

Keywords—Education; student-led learning; STEM; University of Sheffield; Sheffield Space Initiative

I. Introduction

A. Background

The UK is currently experiencing a period of great optimism and activity in the space sector which is being driven by both government backing and private financial investment. Currently Britain controls 5.1% of the global space economy with well developed upstream manufacturing and downstream services. The UK Space Agency aims to help to grow this to 10% by 2030 [1]. The UK Space Industry also impacts positively on public services, national security, science, and innovation [2].

A potential obstacle to this could be a lack of domestic launcher systems which can fracture the supply chain, allowing vulnerability to foreign influence, and bottlenecking of downstream sector growth [2]. The Space Industry Act of 2018 is paving the way for a spaceport and commercial space launches on UK soil, with horizontal launch facilities currently being developed in Cornwall for Virgin Orbit [3]. In terms of private investment, based on the Seraphim Space Index, venture capitalists injected approximately £150 million of funding into 20 UK space companies in the period of September 2017 to September 2018 [4]. The space industry can also contribute wealth to the economy directly and indirectly. In 2017 to 2018, the UK space industry's income grew to £14.8 billion and contributed £5.7 billion to the UK's economic output, representing 0.29% of UK GDP [5].

The 'Size & Health of the UK Space Industry 2018' report clearly identifies that the space industry is not only a growth sector, but also an enabler of growth in other industries such as telecommunication, transport and meteorology [5]. In addition, the space industry's workforce is "exceptionally highly-skilled", with 3 out of 4 workers holding a primary degree. A potential obstacle to the UK's ambitious growth targets is the STEM skills gap. According to Professor Martin Barstow, Pro-Vice-Chancellor of Strategic Science Projects at the University of Leicester, the UK is currently unable to produce enough STEM graduates for the space agency, and it will be necessary to reskill non-STEM graduates. A report by STEM Learning indicated a shortfall of 173,400 workers over 2017 and 2018, which costs STEM businesses an estimated £1.5 billion a year [6].

B. Aims and Objectives

The SSI aims to allow motivated University of Sheffield Students the opportunity to enhance their knowledge of space engineering and project management, and to develop the technical skills and experience that are vital to the industry.

There are currently five active projects within the Sheffield Space Initiative (SSI): SunbYte, SunrIde, SunSat, MarsWorks and Avalon. The projects cover a broad range of upstream and downstream applications, from pushing the boundaries of scientific discovery with SunbYte's solar telescope, to SunrIde's new launch capabilities, exploration vehicles like Marsworks and Avalon, and flexible satellite platforms as with SunSat. Over the course of these projects students work as part of a team to apply the knowledge from their degree programs and acquire new skills. Team members can experience all aspects of a science and engineering mission from conception

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to design, manufacture, integration, testing, and operation. Students can also be exposed to financial and regulatory aspects of engineering projects which are not encountered in normal curricula.

This feeds into SSI's secondary goals, which are to help address the widely reported skills gap in engineering and space engineering in the UK, and to encourage school students to study STEM subjects. Each SSI project dedicates a significant amount of time and resources to outreach and educational activities, in order to inspire and train the next generation of engineers to continue and build on the successes of the projects, and to prepare them for careers within the space industry. To help achieve this SSI members have created the 'SSI Academy', which delivers a series of lectures and workshops at the beginning of each academic year, in which experienced SSI students share their knowledge and experiences with students and members of the public that are interested in space. SSI projects have had engagement with international space agencies like ESA and NASA, as well as major industrial companies, which presents unique advantages and employment opportunities for the members. This paper will assess the impact that the SSI has on former students as well as the wider outreach impact. It will present the lessons learned, and explore its potential use as a model for other institutions to follow.

II. The Projects

SunbYte was the first project of the Sheffield Space Initiative. It stands for the "Sheffield University Nova Balloon Telescope", and is a project which aims to create a robotic solar telescope capable of being lifted by high altitude balloon to an altitude of 30 to 40 km. The purpose of launching the telescope by weather balloon is to lift the telescope above the majority of the atmosphere which can distort the images, i.e. the 'seeing' will be improved. The first version of SunbYte was developed over 2016 and 2017, and was launched in October 2017 on ESA's BEXUS program [7]. A second version was flown with NASA / LSU's High Altitude Student Payload program. During both of these balloon flights, the tracking and pointing system was proven to be effective, although no scientific images were captured [8]. SunbYte III will fly on HASP in early September 2019, and it is hoped that images of the Sun will be captured in the Hydrogen Alpha wavelength of 656.28 nm. This project exposes students to physics, engineering, and project management concepts. The payload must also operate in almost space like conditions of -60 degrees Celsius and near total vacuum pressure. This provides students with a unique opportunity within the SSI to participate in the creation of a payload that operates in near space-like conditions. The next iteration of SunbYte will be one of five payloads to fly on the HEMERA 2020 scientific balloon flight.

Figure 1. SunbYte III at NASA's Columbia Scientific Balloon Facility July 2019

SunrIde is a project to build and launch a rocket. A team of students designed, manufactured, and launched a payload-capable high-power rocket at Spaceport America Cup (SAC) in New Mexico, USA in June 2018. This rocket was entered into the '10,000 feet' category and won, overshooting the target altitude by just 17 feet [9]. A second SunrIde team created a rocket over 2018 and 2019, which was entered in the 2019 SAC in the '30,000 feet' category. The team's rocket was named HELEN after Sheffield Alumni and the first Briton in space Helen Sharman. This rocket set a new UK national record for a student built rocket altitude at 36,274 feet [10]. In addition to setting records, SunrIde also has concrete goals and timelines in relation to outreach and STEM engagement, for instance SunrIde aims to create 200 new rocket engineers by 2024. This complements the UK Space Agency's goal of increasing the UK's space sector workforce from 40,000 to 100,000 by 2030 [11].

Figure 2. SunrIde at Spaceport America Cup 2019

MarsWorks, formerly MoonWorks, is a project to manufacture and operate a rover capable of traversing simulated lunar and martian surfaces, perform tasks, and retrieve regolith samples. The MoonWorks rover was developed over 2017 and 2018 and was entered into the UKSEDS Lunar Rover Challenge, where the team beat 14

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other universities across the UK to claim the Best Innovation Prize, and came 2nd in the Outreach and Critical Design Review categories. Over the course of 2018 and 2019 the project was transformed into MarsWorks, and the team was accepted into the European Rover Challenge which will take place in Poland in September 2019. The initial motivation for MoonWorks was to create a mini rover capable of retrieving ice samples from the lunar surface, as it is anticipated that ice will be an important component of fuel and sustenance if the Moon were to become terraformed. The Mars rover designed by the team will compete in 4 field trials: science; maintenance; collection; and traverse. In addition to these, the team is required to prepare a preliminary and final report, as well as a promotional video and presentation.

Figure 3. Marsworks at The University of Sheffield's iForge makerspace

The Avalon ROV group was started in 2017 with the aim of creating an underwater ROV - Remotely Operated Vehicle - to participate in the MATE ROV Competition. Avalon was the first English team ever to enter the MATE ROV competition. The competition challenges teams to solve real-life underwater problems such exploring Europe's oceans and installing turbines underwater for power generation. The project allows members to learn robotics, electronic and mechanical design, and computer vision. Avalon qualified for the international competition in the USA in 2017, 2018 and again in 2019. This year Avalon was the top team from the UK, 11th overall, and 9th in the product demonstration at the international finals.

Figure 4. Avalon at the 2019 international competition in Kingsport, Tennessee, USA

The newest SSI team is SunSat, which was set up in 2018. The purpose of Sunsat is to create a cubesat service module which will provide a standard interface for ADCS, power, and telemetry for small scientific and technology demonstration payloads. The team aims to simplify the process for payload development by enabling rapid integration into a low-cost standardised satellite bus resulting in shorter time to launch. The team also aims to work closely with the European Space Agency through its various educational programmes and startup opportunities to take this concept into the commercial market.

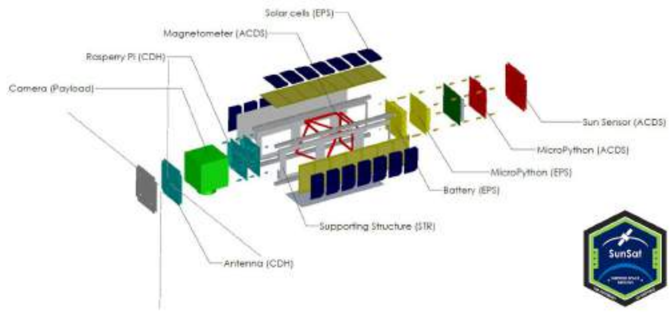

Figure 5. SunSat Computer Aided Design Satellite Architecture

III. Real-World Experience

In total the SSI group of 2018 / 2019 has 108 members across several degree programs. A breakdown of members by gender, area of study, and degree type is shown in Fig. 6 and Fig. 7 below. The SSI project groups place a particular emphasis on STEM outreach for female students, for instance all projects display their payloads at the University of Sheffield's STEM For Girls fair every year.

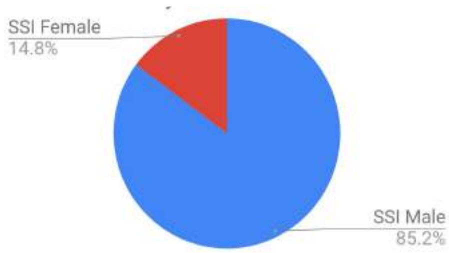

Figure 6. SSI Members by Gender

The diversity of academic backgrounds across the teams reflects real world workplaces by giving team members the experience of working in multi-disciplinary teams. Students can also learn soft skills such as communication, teamwork, and flexibility, as well as managing finances and financial paperwork. Student projects cannot survive without funding and online visibility, therefore in addition to engineering and science backgrounds, each project needs students from humanities backgrounds to assist in the vital tasks of management of social media and applications for funding and competitions.

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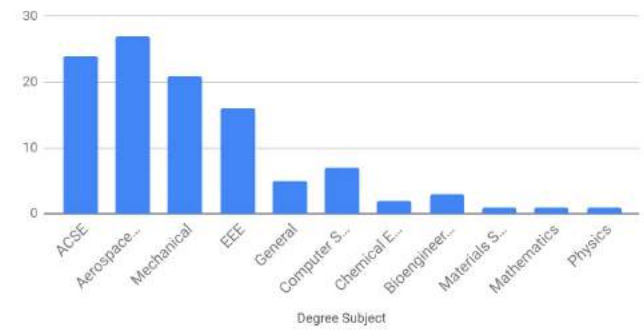

Figure 7. SSI Members by degree Subject

IV. SSI Academy - Knowledge Transfer

The idea of an 'SSI Academy was suggested by one of the student members, and was set up in early 2018. Typically, the team members of each project change year to year, as people leave the university or prioritise final year studies. As they leave, their knowledge of the unique designs is lost, and must be re-taught or re-learned over the next academic year. There are skills which are common to all of the SSI projects, including computer aided design, coding, team management, and electronic / electrical engineering, which may not be familiar to everyone due to their year of study or the focus of their degree subject. It was recognised that there was an opportunity to teach new entrants to the projects all of the skills that they might need or were interested in at the beginning of the academic year, which maximises the time available to work effectively on the project. This knowledge is passed on in the form of extracurricular lectures and workshops with academic staff and experienced team members.

V. Outreach

Outreach is important to each of the projects, and to SSI in general. All of the team members recognise that the projects need enthusiastic students to take over the projects to continue and improve them when they leave the University of Sheffield. To make sure that there will always be skilled and motivated students available to take over the projects the University of Sheffield needs good quality STEM students and school students that enjoy STEM subjects. The projects regularly apply to attend STEM education events and open days for primary and secondary school students, and bring their payloads and several team members in order to pique interest and ensure that any questions that curious students may have can be answered. It is hoped that SSI's outreach efforts will result in more STEM graduates available to continue the projects and fill the skills gap across the space and STEM industries.

Figure 8. SunSat Operations Manager at Pint Of Science event

Figure 9. Avalon in the 2018 Maker Fair in Newcastle

VI. Evaluation

An anonymous five question multiple choice survey was sent to all SSI project members, to assess the impact of their involvement in their project on their career and future career. The survey suggested that the SSI has a very positive impact on participants. The majority (about 70%) of SSI are members are undergraduate students, and 50% reported that their involvement in their project has already helped them secure a job or internship. All respondents also felt that their involvement enhanced their knowledge and understanding of space engineering, and 75% felt that their experience of their project has influenced their career path in the direction of engineering in the space sector.

VII. Conclusion

In conclusion, the University of Sheffield has managed to build up a thriving and dynamic group, which uses student-led learning techniques to enhance higher education. It is hoped that these projects and experiences will help to equip the students for professional careers in both research and industry. Students from other universities wishing to increase their knowledge of space engineering and augment their CV whilst studying for their degree could, with the assistance of an academic, search for student space engineering competitions and begin their own projects. As the project work must be done alongside normal study, it is recommended that as with the SSI academy, all team members should be trained as early as possible in the academic year to increase the amount of

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time available to design, build, test, and acquire funding. For more information, please visit: http://ssi.group.shef.ac.uk

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PW-Sat3 - third iteration of CubeSats developed at Warsaw University of Technology. Mission definition and feasibility study process description.

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***Abstract*—This paper consists of the description of Students' Space Association activities, knowledge transfer process in PW-Sat, mission definition workshops and methods applied during feasibility study of PW-Sat3.**

Keywords—concurrent engineering, ECSS, mission definition, system description.

I. Students' Space Association Initiative

Students' Space Association is placed at the Faculty of Power and Aeronautical Engineering, Warsaw University of Technology. It is the largest student organization at WUT, with approximately 110 active members. Education is its main goal. Organization consists of four main divisions: Rockets, Robotics, Balloons and PW-Sat. Students' Space Association members are also participating in different space projects, e.g. organized by ESA REXUS/BEXUS programme or IGLUNA programme organized by Swiss Space Center.

A. Satellite programme

PW-Sat is the most complex programme among all the Association activities. The first project started in 2005. After 7 years of development, with great help of Polish Space Research Centre, the satellite was launched to orbit onboard Vega rocket on its maiden flight on February 2012. PW-Sat was a 1U CubeSat - the first Polish satellite ever. Its main mission was to test a drag tail, made of flexible solar panels. Due to poor power budget at the early phase of the mission and problems with communication PW-Sat tail eventually was not deployed.

PW-Sat2 project started in January 2013. The team decided to continue with the deorbitation technology development. The final project experiments consisted of 4m2 deorbit sail , in-home built sun sensor, solar panels deployment system and two cameras to capture the sail deployment and confirm its proper functioning. PW-Sat2 was launched on SpaceX's Falcon 9 rocket on 3rd of December 2018. From the beginning the mission was going well. Main experiment - solar sail was deployed on 29th December 2018. After that time the team was expecting to observe lower power production and

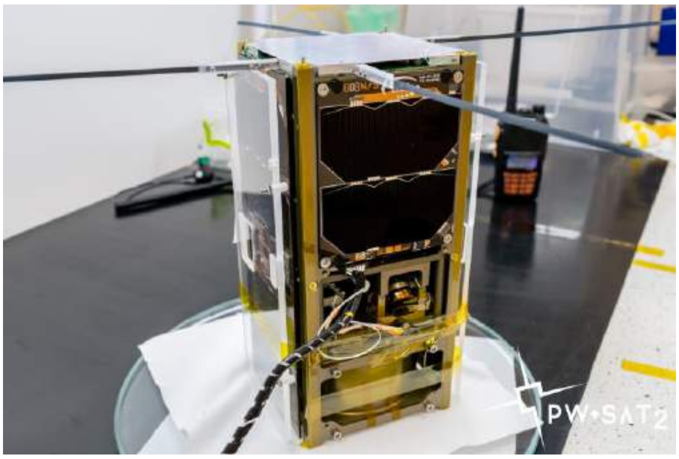

Fig. 1. PW-Sat2 during the final assembly.

eventually even for satellite lost. However, it did not happen. After the sail deployment it was discovered, that the sail structure was torn. Currently, PW-Sat2 is still in orbit and communication is constantly sustained. The satellite is gradually lowering its orbit. More information about PW-Sat2 project can be found at https://pw-sat.pl/en/home-page/. In October 2018 the team started to develop PW-Sat3 satellite, which is widely described in next chapter of this paper.

B. Transfer of knowledge

In all Students' Space Association activities internal transfer of knowledge plays a major role for organization development and allow its divisions to build more and more complex projects.

Every year approximately 50 students who successfully finished their recruitment projects join the Association. Usually their first duty is to attend lectures conducted by experienced members and learn as much as possible about current and previous projects conducted by the division they want to join. When PW-Sat3 project was starting for first two months main activity of its members was attending workshops conducted by PW-Sat2 team leaders. These workshops included topics such as mechanical design, thermal control system, electronics, software, design and testing requirements.

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Fig. 2. PW-Sat2 onboard camera photo with torn structure of deorbit sail.

This wide range training allowed PW-Sat3 team to smoothly start the project and avoid unnecessary early stage problems.

C. Organization activities outcome

All activities performed by members of the Association have great influence on what happens in Polish space sector and raises social awareness about space exploration.

Students, who leave the Association usually join companies from space industry or set up their own business in this sector. Among them one can find the most important space related companies such as Airbus, Thales Alenia, SENER, GMV, but also fast-growing Polish companies e.g. Astronika, CreoTech or science and research institutions such as Polish Institute of Aviation or Space Research Centre.

Social aspect of Association actions is also significant. The organisation members participate in many events, where students inform attendees about developed projects and sparks curiosity about space, especially among youngsters.

II. PW-SAT3

A. Mission definition

The primary mission experiment is a propulsion system for controlled orbit traverse. A cold gas thruster is being designed to achieve the demanded circular orbit. It was decided to apply one nozzle for impulse generation in desired direction. For this operation, and to stabilize the satellite during and after the orbital maneuvers ADCS (altitude determination and control system) with reaction wheels will be in use. The propulsion system is a *cold gas* thruster with butane as a propellant and industrial valves, with no space heritage, are considered to be applied.

The mission plan includes preheating the butane and use of heating coil inside which the propellant will be transferred to the nozzle.

B. Feasibility study process description

PW-Sat3 phase A lasts from March 2019. During this time, technical budgets, components trade-offs, requirements and significant decision about the mission simplification were made. The approach for this phase of development was based on knowledge and methods gathered during CubeSat Concurrent Engineering Design Workshop 2019. Use of Open Concurrent Design Tool for budgets, simulations and preliminary components list definition inspired PW-Sat3 system engineer to create similar tool for these tasks. Shared Google Sheets used during team workshops organized weekly let to first budgets and CubeSat design sketch in one month. Mechanical and power consumption data were gathered in one document with links to datasheets with more accurate information. To ensure that components will fit to mass, volume and power constraints, margins were set according to the policy introduced to members of CubeSat Concurrent Engineering Workshop 2019. The requirements design based on ECSS (European Commision for Space Standarization) Applicability Requirements Matrix with strong simplifications let to define crucial payload parameters needed to be tested as well as shortages in specialist knowledge. Ways to tackle with the problems were defined. The requirements were considered by the subteam and then discussed by whole team and accepted by the system engineer. To make sure that members are familiar with project status, current tasks lists for the subteams and manager are available for all team members. Kanban methodology is applied for tasks management.

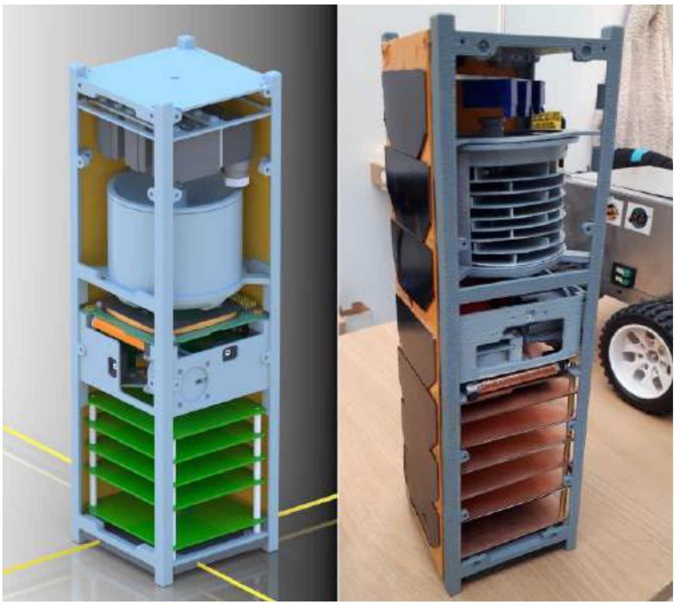

Fig. 3. Up-to-date PW-Sat3 design, together with first, 3D printed satellite model.

The next stage of the feasibility study is the propulsion system testing and facility development. Tests output data is necessary for detailed ADCS requirements definition. The facility was also the first opportunity to get familiar with designed mechanical components being part of PW-Sat3 main

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payload and give the students a motivation for further progress.
To check if the volume budget and components placement is designed properly, 3D printed model was created and integrated to check if the assembling process is possible and find the best way of going through it.

C. Development plans

One of the most important technical problems in PW-Sat3 is to ensure negligible propulsion slosh impact on ADCS design. This is why the tank containing the propellant will consist of the anti-slosh system which is in the development phase now. To control internal tank pressure and reduce liquid butane escape from the system, heating subsystem is being developed. As a part of considerations from phase 0, the reaction wheel is being designed as potential payload. Other PW-Sat3 components are being developed in varied tempo according to the needs of the whole project and current workforce which is monitored by shared sheets. By the end of 2019 the preliminary test campaign for the propulsion system will be done together with finishing the trade-offs for COTS (components of the shelf) and development options for any designed subsystem.

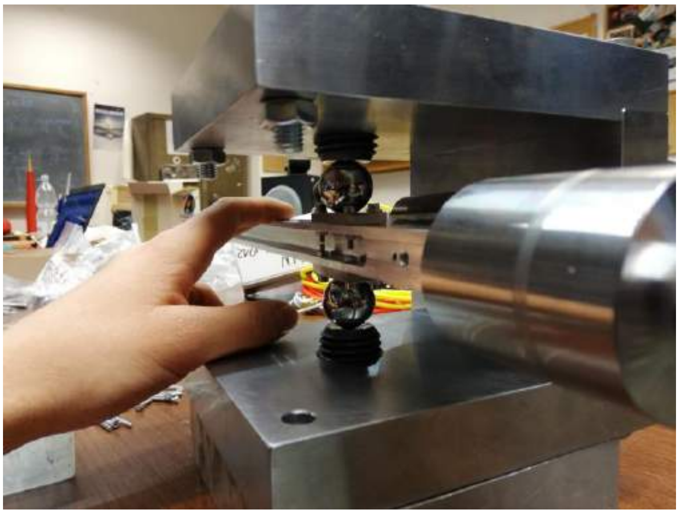

Fig. 4. Torosional pendulum based thrust stand developed for propulsion system test campaign, during its itegration.

The phase of preliminary design of PW-Sat3 will begin. PW-Sat3 launch is planned for the last months of 2022.

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THE IMPORTANCE OF A SIMPLE ASTRONOMY CLUB IN A SCIENCE-CLOSED CITY

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Abstract— Manaus is a city in the heart of the Amazonian Rainforest that did not have any scientific interest whatsoever. My city lives in a constant fight against any kind of scientific relevance, that causes a population that lacks the most basic understanding of how our universe works, since 2016, a group that I'm part is working to make this situation better, we formed an Astronomy Club in our University, since the city had none like it, and we observed some changes after our work to disseminate science started. First, people of the city started to attend more and more to scientific events that started showing up here and there, then, some events that were only about pop culture and other kinds of entertainment started asking our presence to participate and spread our knowledge to the more common folk. This work continued and more and more people are starting to see science differently, with this job we want to create a more open-minded city to new experiences in astronomy, physics and other matters. **Keywords— City, Astronomy, People.**

NOMENCLATURE

CAUFAM: Clube de Astronomia da Universidade Federal do Amazonas. (Astronomy Club of the Federal University of Amazonas)

UFAM : Universidade Federal do Amazonas (Federal University of Amazonas)

I. INTRODUCTION

Manaus is a city deep inside the Amazonian rainforest, it is the capital city of Amazonas and is composed of 2,145,444 people, despite being the 7th largest city in Brazil [1] it suffers from a big problem, the lack of scientific growth and propagation. A big chunk of the problem comes from the poor educational system and almost non-existent scientific events in the city, to try and solve this problem, in 2016 a group called the CAUFAM was born to try and solve the lack of scientific content in the city, founded with the purpose of spreading scientific knowledge around town and try to make our city a better place, we started to provide astronomical observations with 2 telescopes provided by the UFAM, since most people around town never had the chance to have a close look at the stars and planets in the night sky. The club changes its personnel every year, though many of our participants stay until this day in our club, most of its members change to provide a new experience every year to new people. Through the years our work showed to be relevant and led to some interesting conclusions, in this paper those conclusions are going to be exposed and analyzed so others can try and replicate these actions to your own cities or counties.

II. METHODOLOGY

Between the years of 2016 and 2018 the CAUFAM did weekly observations of the night sky, covered 9 major astronomical events such as full moon eclipses, partial moon eclipses and partial sun eclipses, these observations had the purpose of spreading science around town and oppose misinformation. In these 3 years, the CAUFAM had in total 53 participants that helped in regional events in and out of town, these events covered 5 schools composed of students of varying ages, including adults that were doing high-school again, there were also 6 events downtown and 1 in the slums, were we aimed to reach marginalized people that had were illiterate, and mostly children and teenagers that never thought they could be scientists. Beyond night sky observations, we did astronomy workshops that tried to show that science was not far away from them, but really close to their reality.

III. RESULTS AND CHALLENGES

During the 3 years we encountered many problems, including rain, cloudy skies, bad organization in the schools and places that events were set. Rain was the main issue with our work, and being in a tropical region made it a pretty hard job to do consistently, the solution for that problem was starting to make workshops in the daylight at different places and schools, that brought us to a new perspective on the younglings, they were unaware that science could be so fun and enlightening.

The second main issue was the lack of interest in schools and some participants of the club to work in the projects and workshops, this made us rethink our recruitment process and change some of our participants, that didn't make so much difference because some schools didn't gave us the amount of aid that we needed, causing our transportation and application of workshops much harder.

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Despite the challenges that we faced, the results were very satisfying, in the 3 years of application, we could affect more than 8,000 people, including not only kids and teenagers, but women and men of various ages, from early 20s to late 70s, and the biggest surprise on the project was that many of the older people were mesmerized and some cried because some of them never saw the moon close-by or the planets, this was a turning point in our project, and gave us data to work with the elderly.

At the end of 2018 we saw that our work created a greater relevance in science at our city, with the creation of events such as the First Week of Indigenous Astronomy [2] and made our presence in other events of our town an attractive opportunity for people to go and learn more.

IV. Conclusion and Future Goals

The 3 years of work resulted in a change of perspective in our town, were science was closer to the citizens and made the scientific career a reality in our schools, where science and scientists were considered almost unreachable became not only a possible dream, but a close one. The continuous work in these three years proved to be satisfactory in the sense of science propagation, over 270 kids from many schools searched us for help in find a way to start studying and applying for science and astronomy careers, in which we aided with the help of our University and started a close relationship with the institution.

Not only the citizens that we worked were impacted by this job, but the students at our University realized that astronomy was a worthy job to follow and came to some realization in the change of their careers.

Our expectations in our continuous work are that more children start aiming for a lifelong career in science, astronomy and education, so that we can open our city for future scientists that will allow us to do more researches, open more labs and observatories.

a.

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Online team work in space science and astronomy at the Open University

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***Abstract* — The UK Open University (UKOU) operates a distance-learning model supporting students who are geographically dispersed and studying part-time. Development of team-working skills is particularly challenging within such a model, but is considered a necessary part of the higher education experience of space scientists and astronomers. We report on three team-working projects in space science and astronomy that we run at the UKOU at advanced undergraduate and taught postgraduate levels. The projects are: (i) an investigation of quasar spectra using data from the Sloan Digital Sky Survey (SDSS), (ii) characterisation of variable star light curves using observations from a robotic telescope, and (iii) a Mars rover mission simulation. The robotic telescope and the Mars rover simulation are part of The Open University's award-winning OpenSTEM Labs. All three projects involve teams of students working remotely from each other and communicating through asynchronous and synchronous (shared audio and whiteboard) methods. The projects are somewhat open-ended and require teams to make collective decisions about their actions. We describe how these projects are being studied in order to better understand the student experience of on-line team-working.**

Keywords — skills development; team-working; remote experimentation.

I. Introduction

The Open University in the United Kingdom, (UKOU) is a distance-learning higher education institution (HEI) providing undergraduate and postgraduate qualifications in a range of curriculum areas. Astrophysics is offered at advanced undergraduate level, and space science is part of a taught postgraduate program, together attracting about 120 and 50 students per annum respectively.

A skill that is important in astrophysics and space science is that of being able to work effectively with others to conduct a scientific investigation. In contrast to students at conventional HEIs, students at the UKOU have very little opportunity to meet face-to-face, and in the subject areas discussed here, all teaching is online. Thus any student group work has to be conducted by students who have only ever met together in an online setting.

Additionally, access to experimental and observational facilities also has to be conducted online. The UKOU has made very substantial progress in opening up remote experiments to students through its OpenSTEM Labs initiative [1].

Here we briefly describe three project activities that develop team-working skills and we present some early results on student interaction and student experience.

II. Team projects in astrophysics

Two different team projects are available to students studying astrophysics. One is based on the use of a robotic telescope to study the light curve of a variable star [2, 3]. In the other, students use the Sloan Digital Sky Survey (SDSS) [4], to investigate the optical-UV spectra of quasars. In both cases the team size is typically 6 to 10 students, and the project runs over 9 study weeks, amounting to roughly 100 hours of study.

A. The robotic telescope project

The UKOU, through its OpenSTEM Labs, operates a robotic observatory located in Tenerife, and telescope time is allocated to student groups for this project. The aim of the project is to constrain the nature of, and determine the physical characteristics of, an unclassified or poorly-studied star that shows periodic optical variability. Up to four observing nights are available to each project group allowing the acquisition of light curves using a range of photometric filters.

B. The SDSS quasar project

The SDSS is a long-standing research project (external to the UKOU) that uses a dedicated robotic telescope to conduct large-scale imaging and spectroscopic surveys. In this project, students are tasked with creating a composite quasar spectrum using SDSS data. By combining spectra from quasars with a range of redshifts, a composite spectrum can be constructed that extends from the visible to UV wavelengths.

III. Team project in space science

The team project for the postgraduate module in space science is a simulation of a Mars rover mission. It has a much shorter duration than the astrophysics projects described above, lasting only one week and about 16 hours of study time. The simulation is based around a Mars yard facility at the UKOU campus in Milton Keynes (UK) and a robotic rover.

The scenario that teams are presented with is that "a small scouting rover has been landed on Mars to assess whether its landing site is suitable for follow-up with a large rover that will search for evidence of past or present life". The goals of the

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mission are; to document the landscape and rock types therein, to seek evidence for water-bearing minerals in those rocks, and to assess the evidence for past or present flowing or standing water. The team is expected to produce daily reports on their findings, and is responsible for the safety of the rover such that it should remain drivable throughout and at the end of the simulation.

The operating environment is a Mars yard (with approximate dimensions 6 m × 12 m) containing rocks that have been selected to be analogues of those found on Mars. The rover used in the simulation is a small, six-wheel 'all terrain' vehicle built using off-the-shelf components

Given the complexity of the rover, the mission team is split into sub-teams with responsibility for particular aspects of the mission. Typically, about 16 students participate in each simulation exercise, with 2 or 3 students allocated to each sub-team.

IV. Analysis

From an educational perspective, our online collaborative projects are of interest for several reasons. Here we highlight two of several research questions that we are investigating:

- How does the content of the student forums vary depending on the nature of the projects?
- Do students perceive that engagement in online team-work activities is important and, if so, why?

A. Forum content analysis

We have analysed the content of the online student forums that are used to support all three types of project. Forum messages, or parts thereof, are classified as relating to one of four broad categories: (i) group building and social interaction, (ii) learning and skills development, (iii) project management, and, (iv) expression of individual feelings. We analysed three forums for each of the three projects (a total of 4,187 forum posts). The proportion of messages or distinct parts of messages in these categories is shown in Table 1.

TABLE I. THE PROPORTION OF DISTINCT PARTS OF FORUM MESSAGES, CLASSIFIED BY INTENT.

	SDSS	PIRATE[a]	ROVER
Group building	16.8%	15.1%	17.9%
Learning	44.8%	37.4%	42.6%
Project management	36.3%	43.8%	37.3%
Feelings	2.1%	3.6%	2.3%

[a] PIRATE refers to the robotic telescope project.

There are broad similarities between the projects, with a distribution which is approximately as follows: group building – 16%, learning – 40%, project management – 38% and feelings – 2%. Given the different nature of the rover exercise (short duration, high level of synchronous communication) to the other two projects, it is notable that the content of the forums is very similar when analysed at this level. There are also interesting differences. The greater emphasis on project management in the robotic telescope project reflects the greater degree of planning and discussion needed to run a relatively complex procedure to acquire data from a telescope. Also, the expression of individual feelings was highest for the robotic telescope project – the forum posts reveal that much of this is both positive and negative sentiments associated with the challenges of operating a real telescope where the observing conditions are variable and there are sometimes technical difficulties to be overcome.

B. Interviews

We interviewed 14 volunteer students (robotic telescope: 3, SDSS: 5 rover: 6) about their experience on these team projects. The interviews addressed sixteen aspects of the student experience on these team projects. Here we report on the responses to one question: *"Do you think it is important for students to engage in this type of group activity?"*

The relevance of team-working to employment in the space-sector, or more generally, is clear to most students. The majority of interviewees identified clear links to employability with comments such as *"if you want to work in science now, you have to collaborate with people all the time"*, and, *"it's a key skill that's important to employers in the real world"*.

About half the respondents mentioned that team-working is valuable because it provides a social environment for their learning. Some mentioned the satisfaction obtained from being part of a joint-enterprise. Others reflected on the fact that being in a group can be challenging, but that their response to that challenge had been a development in their skills: *"for me it's slightly out of my comfort zone, but I got more from it than anything else"*.

V. Conclusions

Online team projects in space science and astronomy at the UKOU provide a way to give distance-learning students some experience of working together in a way that reflects the way that scientific investigations are actually carried out. There are similar patterns of forum interaction between projects, but with some notable differences. We have also found that generally, students do appreciate the importance of team-working activities both for their own learning and their employability.

Acknowledgment

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Assembly, Integration and Verification Activities for a 2U CubeSat, EIRSAT-1

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***Abstract*—The Educational Irish Research Satellite, EIRSAT-1, is a project developed by students at University College Dublin that aims to design, build, and launch Ireland's first satellite. EIRSAT-1 is a 2U CubeSat incorporating three novel payloads; GMOD, a gamma-ray detector, EMOD, a thermal coating management experiment, and WBC, a novel attitude control algorithm. The EIRSAT-1 project is carried out with the support of the Education Office of the European Space Agency, under the educational Fly your Satellite! programme.**

The Assembly, Integration and Verification (AIV) plan for EIRSAT-1 is central to the philosophy and the development of the spacecraft. The model philosophy employed for the project is known as the 'prototype' approach in which two models of the spacecraft are assembled; an Engineering Qualification Model (EQM) and a Flight Model (FM). The payloads, GMOD and EMOD, and the Antenna Deployment Module (ADM) platform element warrant a Development Model (DM) in addition to an EQM and a FM, as they have been designed and developed in-house. The engineering qualification model serves as both a FlatSat for electrical integration testing and as a representative model for testing of software code, patching and operational decisions during the active mission. The EQM is tested to qualification levels and durations during the environmental test campaign. The flight model contains the flight versions of the payloads, ADM platform element and the procured hardware elements. It undergoes acceptance level testing and it is the final spacecraft to be delivered to ESA for flight.

After successful completion of the Critical Design Review (CDR) and Ambient Test Readiness Review (ATRR) phases of the project, the EQM of EIRSAT-1 will be assembled and integrated in University College Dublin. After assembly and integration of the EQM, the project will begin the ambient test campaign, in which the EQM undergoes ambient functional and mission testing. This work details the preparation and execution of the assembly, integration, and verification activities of EIRSAT-1 EQM.

Keywords—CubeSats, EIRSAT-1, Fly Your Satellite!, Assembly Integration & Verification.

I. INTRODUCTION

The Educational Irish Research Satellite [1], EIRSAT-1, is a student led project which aims to design, build, launch and operate Ireland's first satellite. Selected in 2017 by ESA Education's Fly Your Satellite! (FYS) programme, EIRSAT-1 is a 2U CubeSat (Fig. 1) being developed at University College Dublin (UCD). The mission carries three payloads; a gamma-ray detector, the Gamma-Ray Module (GMOD), a thermal management surface treatment experiment, the ENBIO Module (EMOD), and an attitude control algorithm, Wave Based Control (WBC) [2]. The EIRSAT-1 project is primarily educational, aiming to develop the know-how of the Irish higher education sector in space science and engineering and to address skills shortages in the Irish space sector.

The Assembly, Integration and Verification (AIV) plan describes the overall Assembly, Integration and Testing (AIT) activities and the Verification Plan (VP) of the project. It is used to prepare the Assembly and Integration Procedure (AIP) and the Test Specification and Test Procedures (TSTP). The AIV plan of EIRSAT-1 describes the 'prototype' model philosophy that has been adapted for the project, the main activities in the assembly and integration process, and the tests carried out at subsystem and system level. The overall objective of verification is to demonstrate that the deliverable spacecraft meets the specified requirements. It demonstrates the qualification of the design and it confirms that the overall system is able to fulfil the mission requirements.

This paper details the AIV activities performed in preparation for the launch of EIRSAT-1. Section II describes the model philosophy for the project with particular focus on the system level and on the in-house developed elements. Section III discusses the preparation for ambient testing. Section IV details the ambient test campaign for EIRSAT-1 while Section V details the environmental tests that will be performed.

II. MODEL PHILOSOPHY

The model philosophy defines the optimum number and the characteristics of the physical models produced to achieve confidence in the product, while weighing both the costs and risk involved. The model philosophy of EIRSAT-1 follows a 'prototype' approach. The prototype approach offers the project minimum risk, completion of qualification activities prior to acceptance, and the capability to use the Engineering Qualification Model as an integration spare at system level. For EIRSAT-1, the approach is covered in three main steps:

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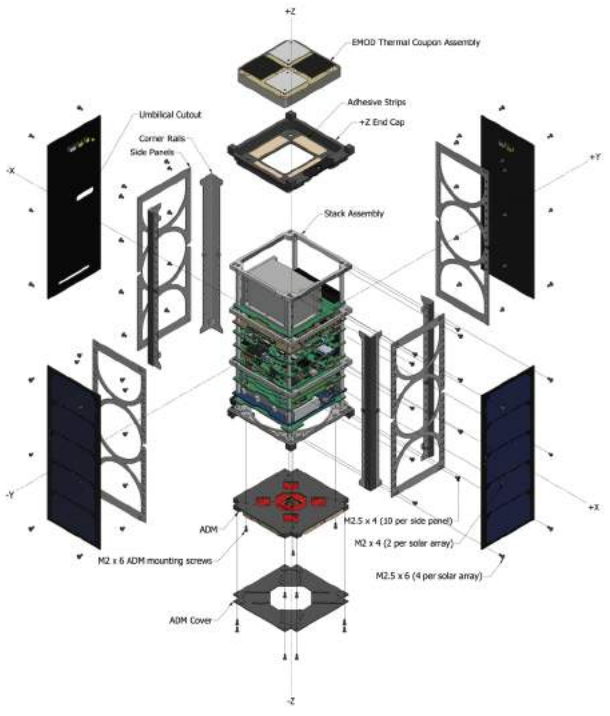

Fig. 1. Exploded view of EIRSAT-1.

- Development Model (DM)/Element Testing.
- Engineering Qualification Model (EQM).
- Flight Model (FM).

Development models are produced for all elements of the spacecraft that are new developments and are not off the shelf. These elements are being developed in UCD and are most notably the payloads, GMOD, EMOD, and WBC, and the Antenna Deployment Module (ADM). These models allow confirmation of the design feasibility of the element. They are designed in an iterative process whereby each element DM is designed, assembled and tested at unit level until all functional, electrical, and software requirements are in agreement with verification objectives. For elements that are commercial off the shelf (COTS), two one-off amounts are procured to have one set each for the spacecraft EQM and FM.

A. Spacecraft

Two models exist at the spacecraft level – the Engineering Qualification Model and the Flight Model. The EQM is made up of the EQMs of the payloads, the ADM platform element and the procured subsystems. The model serves both as a FlatSat for electrical integration testing and also as a representative model for testing of software code and for operational decisions during the active mission. The model provides the functional qualification of the design and the interfaces between subsystems. It undergoes testing to qualification levels and durations. Any feedback from qualification testing of the EQM is taken into account when manufacturing the FM. The FM consists of the flight COTS subsystems, the FM payloads and the FM ADM. It is the end product that is intended for flight and is subject to functional and environmental acceptance level testing before delivery to ESA.

The design of both the EQM and FM is identical, within the project constraints. Producing both an EQM and FM at system level has significant costs for the project but hugely reduces the risk involved. To save on cost, the EQM does not include solar cells. However, suitable custom boards have been produced to mimic the magnetorquers and Coarse Sun Sensors (CSS) of the ADCS subsystem to allow for testing on the EQM.

B. GMOD Payload

GMOD is an experiment designed to detect cosmic gamma-ray phenomena such as Gamma-Ray Bursts (GRBs). The payload can be considered in two parts: the detector assembly and the motherboard. The detector assembly contains a $CeBr_3$ scintillator, a 4 x 4 Silicon Photomultiplier (SiPM) array and an Application Specific Integrated Circuit (ASIC). The motherboard has been designed in-house and contains the supporting electronics of the detector assembly.

The GMOD detector assembly will have an EQM and a FM, which will be identical. Therefore, the EQM can serve as a flight-spare or on-ground debugging tool. The mature design of the detector assembly does not warrant a DM. The EQM will undergo environmental testing at unit-level before being integrated with the full spacecraft EQM. An additional model will be produced to undergo shock testing, verifying the functionality of the payload after encountering the loads of the launcher. While the detector assembly does not require a DM, the low cost associated with the motherboard components meant that producing development models significantly reduced the risk associated with the GMOD payload. The GMOD motherboard underwent a design process in which multiple development models were manufactured until the final design of the board was accepted. The final DM of the motherboard (DM3) is the design on which the EQM and FM are based.

C. EMOD Payload

EMOD is an experimental payload designed to evaluate the in-flight performance of two thermal spacecraft coatings developed by ENBIO Ltd. The experiment consists of the Thermal Coupon Assembly (TCA), which is affixed to the +Z face of the spacecraft, and the motherboard. The TCA accommodates four ‘thermal coupons’ which have been treated with SolarBlack or SolarWhite thermal control coating. The temperature of the coupons will be monitored throughout the lifetime of the EIRSAT-1 mission.

The EMOD TCA has a DM, an EQM, and a FM. The DM was developed to conduct adhesion and outgassing tests of the ENBIO adhesive primer [3]. The EQM and the FM shall be identical and so the EQM can act as a flight-spare or on-ground debugging tool. The TCA EQM will undergo environmental testing at unit level to verify the design and workmanship of the assembly. Like GMOD, the design of the EMOD motherboard was finalised after an iterative process. The final DM (DM4) of the motherboard is the design for the EQM and FM.

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D. Antenna Deployment Module

The ADM [4] holds two dipole antennae and is attached to the –Z end cap of EIRSAT-1. The deployment mechanism uses pairs of melt-lines that hold spring loaded doors in a closed position. The lines are burnt during deployment to allow the antennae to uncoil into their straight deployed configuration.

The ADM model philosophy follows that of GMOD and EMOD consisting of a DM, an EQM, and a FM. The ADM has undergone extensive design and testing due to its significance in performing the mission. A mechanical prototype (DM) of the element was manufactured and was tested under both ambient and environmental conditions to verify the mechanical functionality of the design. In parallel with the development of the mechanical design, the electrical design and the efficiency of the antenna elements in terms of the communications subsystem have been configured and tested. At DM level, two parallel designs were implemented on Printed Circuit Boards (PCBs) and the radiation pattern of both were tested. A PCB design was chosen after testing as the final design of the ADM PCB, which will implemented for the EQM and the FM.

III. Ambient Test Readiness Review

The Ambient Test Readiness Review (ATRR) for EIRSAT-1 began in June 2018. The review process involved the preparation of the Assembly and Integration Plan and of the Test Specification and Test Plan (TSTP) for all tests to be carried out during the Ambient Test Campaign (ATC). These procedures were subject to a review process from ESA and review item discrepancies (RIDs) were issued to the team. After the closure of the RIDs, the EQM of EIRSAT-1 was assembled.

A. Assembly and Integration Plan

The assembly and integration plan of EIRSAT-1 defines the step-by-step procedure that is followed during assembly of the EQM and the FM. The requirements and steps outlined in the document must be followed in detail to ensure that the spacecraft is assembled correctly. The main steps taken to assemble and integrate both the EQM and FM of EIRSAT-1 are illustrated in Fig. 2.

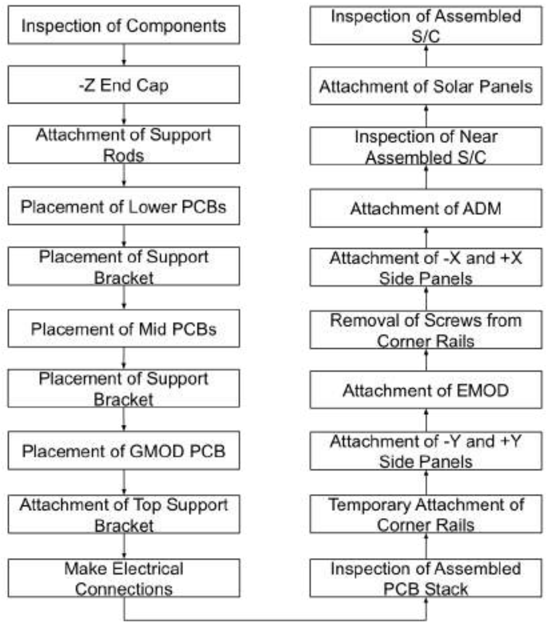

Fig. 2. Flow chart of the assembly and integration activites for EIRSAT-1.

Before the assembly and integration of the main spacecraft begins, the deployment switches are installed to the corner rails while thermocouples are installed to the subsystem PCBs. Thirteen thermocouples are used during the environmental test campaign to monitor the internal temperatures of certain subsystems. These thermocouples are installed to the spacecraft using a combination of kapton and aluminium tape for the EQM while a non-conducting epoxy glue will be used for the FM. The assembly and integration process begins from the bottom of the stack assembly with the –Z end cap. The four support rods are attached to the end cap and an orthogonality check of the rods is performed using a support interface rib. Next, the PCBs are placed onto the stack in the order of the Z-axis magnetorquer (MTQ), Communications (TT&C), Battery, Electrical Power System (EPS), On Board Computer (OBC), Attitude Determination and Control System (ADCS), EMOD motherboard, and finally, the GMOD motherboard and detector assembly. Two support brackets are placed in the stack, one between the EPS and the OBC while the other is located between the EMOD and GMOD motherboards. All PCBs and support brackets are supported by 4 spacers, one on each of the four support rods, and the PCBs are electrically connected by the 104-pin header at the +Y face of the stack. As each PCB is placed on the stack assembly, any harnesses for that PCB are connected and are routed through the stack. Finally, the upper support bracket is secured to the +Z ends of the support rods to complete the PCB stack assembly. The next step of the assembly process is to attach the side panels. The M2.5 screws that hold the side panels in place also fix the corner rails to the structure of the spacecraft, and so the corner rails must be temporarily attached to the PCB stack. The rails are attached by nylon screws which are inserted into the corner rail clearance holes at the –X and +X faces of the spacecraft. This allows the side panels to be mounted onto the –Y and +Y faces using the desired M2.5 stainless steel screws. Next, the EMOD payload is integrated to the spacecraft and the +Z end cap is secured to the corner rails. The temporary nylon screws are removed from the rails so that the +X and –X side panels can be mounted to the spacecraft. The ADM is then attached by rotating the CubeSat by 180° in the integration stand so that the –Z end cap is now accessible. The outer cover of the ADM is removed and the ADM is secured to the –Z end cap by 4 M2 mounting screws. The outer cover is then replaced back onto the ADM. Finally, the solar panels are mounted onto the spacecraft. The order of the solar panel mounting is –Y, +X, +Y, and –X. The ordering of the solar panel attachment is to facilitate the routing of thermocouple cables that are attached to the back of the solar panel PCBs. All thermocouples which are placed throughout the spacecraft for use during environmental testing exit the spacecraft through a 50mm x 5mm cut out in the –X solar panel.

Various inspection points are performed during the assembly process. These inspections occur once a central part of the spacecraft has been assembled, such as after the PCB stack assembly, after the side panels have been attached and finally,

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once the spacecraft has been fully assembled. These inspection points allow the operators to note any defects or anomalies during the assembly process to reduce the risk of failures during the test campaigns that follow.

B. Mass and Dimension Verification

After the assembly and integration of EIRSAT-1, the mass and the dimensions are measured to verify that the CubeSat is within the limits of mass and dimensions as required by the Fly Your Satellite Design Specification (FDS). When fully integrated, the EIRSAT-1 spacecraft is expected to be 2066g, compliant with the requirement of 2660g for a 2U CubeSat.

C. Phase D Workshop

In April 2019, a Phase D Workshop was held by ESA Education and FYS. The EIRSAT-1 team presented a representative model of the EQM (Fig. 3) which incorporated the EQMs of the Z-axis MTQ, TT&C, OBC, Battery, EPS, and structure subsystems; the DMs of the ADM, GMOD, and EMOD; and a dummy PCB for the ADCS subsystem. During the workshop, the mass and dimension verification of the model was performed. The mass was measured as 1681.7g, less than the total expected mass of EIRSAT-1 due to the scintillator crystal not being present in the GMOD detector assembly and a dummy PCB being present for the ADCS subsystem.

The dimensions verification was carried out for the CubeSat's width and height. The width of the model was measured at the top, middle and bottom of the main structure and at the +Z and –Z end cap rail standoffs for each of the –X, +X, –Y and +Y sides of the unit. All measured values were compliant with the requirement of 100.0 ± 0.1mm. The height of the spacecraft was measured for each of the four corner rails from the –Z to the +Z end cap rail standoffs. All measurements were compliant with the requirement of 227.0 ± 0.2 mm for a 2U CubeSat. A further verification of the dimensions of the CubeSat were carried out by insertion into a CubeSat deployer. An inspection verification of the model was performed during which the exterior of the CubeSat was inspected for any visible damage. During the inspection, any scratches to the exterior were noted.

IV. Ambient Test Campaign

The ambient test campaign for EIRSAT-1 is planned to begin in October 2019. It is expected to last 3 months after which test reports (TRTPs) for all tests carried out during the campaign will be submitted to FYS! for review. All test activities to be carried out during the ambient test campaign have a separate Test Specification and Test Procedure. The Test Specification describes the test requirements applicable to a related test activity while the Test Procedure gives the directions for conducting the test. The documents are written with such level of detail that different test operators can obtain the same results when executing the procedure. The step-by-step procedure is used to conduct the test and is filled in throughout. It becomes the core section of the test report. The two main tests to be carried out during the ambient test campaign for EIRSAT-1 are the functional test and the mission test.

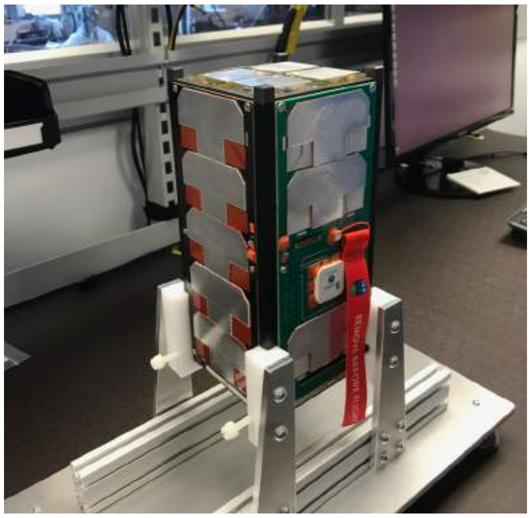

Fig. 3. Assembled representative EQM of EIRSAT-1.

A. Functional Test

Functional testing verifies the complete function of the spacecraft, under the specified operating and environmental conditions and in all operational modes. Functional tests are carried out on both the EQM and the FM models of EIRSAT-1 and occur at the beginning and the end of various test activities such as thermal vacuum and vibration testing. The test includes testing mechanical functions, electrical functions and operational functions of the spacecraft. The functional test planned for EIRSAT-1 consists of the following:

- Visual inspection.
- Antenna deployment of all elements testing the primary and secondary melt-line deployment mechanisms.
- Testing of all operational modes and the CubeSat separation sequence including removal of Remove Before Flight (RBF) pin, deployment of activation switches, antenna deployment.
- Battery and EPS testing including battery charging via solar cells and charging tether cable, EPS protection functions, battery discharging, EPS trip recording, low battery boot up, and RBF pin insertion.
- Flashing of GMOD and EMOD firmware.
- GMOD functionality including burst detection, sensitivity to laboratory source, and processing of light curves and spectra.
- EMOD functionality including polling temperature data and varying the data acquisition rate.
- WBC functionality including testing of ADCS modes.
- Software reprogramming from the ground for any updates or bug fixes made to software.

B. Mission Test

The mission test ensures that the spacecraft is capable of performing the required mission when in-orbit, by simulating in-flight operations, sequences and hardware/software interfaces that will (or may) occur over the lifetime of the mission. This test includes the main, critical, and contingency operations that

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are foreseen for the mission. To perform this test, the entire mission profile is simulated as if in-flight, within the constraints of a ground-based test facility. Within the mission test, end-to-end testing will also ensure that the ground segment, as well as the space segment, is capable of operating as required for the success of the mission. EIRSAT-1's mission test will simulate the following mission scenarios:

- Deployment and the separation sequence including removal of RBF pin, deployment of activation switches, antenna deployment.
- Initial Acquisition of Signal (AOS) pass.
- Nominal pass, including a prolonged nominal pass.
- WBC mode entry for both a scheduled and requested telecommand.
- Automatic transition from WBC mode to safe mode in case of attitude parameters exceeding the predefined limits.
- Safe mode entry and exit.
- Hard reset of the spacecraft.
- Watchdog timer reboot after a prolonged period of silence from the ground station.
- Transmission inhibit in the event of a request to cease transmissions of the spacecraft for a period of time.
- Force mode change from the current operational mode to another.
- Power cycling of the payloads.
- Operating on a low battery level.
- Uploading and booting to a new software image.

V. Environmental Test Campaign

The environmental test campaign for EIRSAT-1 will begin after successful review of all ambient test reports, which is planned for early 2020. During the environmental test campaign, the EQM is tested to qualification levels to verify that the design and manufacturing technique fulfill specification requirements. It accounts for severe hardware characteristics which can be present in a flight unit. The FM will be tested to acceptance levels to check the workmanship of the flight hardware and to avoid inducing additional stress on the unit that may lead to a failure during the mission.

A. Vibration Test

The vibration test will be the first environmental test to be carried out at system level as it will be the first environment encountered during the mission. The vibration test aims to replicate the launch mechanical environment that EIRSAT-1 will experience. To give confidence in the design of the spacecraft before testing, modelling and analyses were carried out to assess the stress and displacement patterns of EIRSAT-1. The analysis provides the locations of the spacecraft and the vibration frequencies that should be monitored closely throughout the vibration test. The test will consist of a modal survey, random vibrations, and sinusoidal vibrations of all 3-axes of the CubeSat. EIRSAT-1 will be placed within a CubeSat deployer for the duration of the test as this will be its configuration for launch. Dummy masses will also be inside the deployer to replicate nearby CubeSats. Sensors will be placed on EIRSAT-1 during the test to measure the displacement and acceleration of the CubeSat.

Vibration testing will take place at the CubeSat Support Facility of the ESA Education Training Centre. The facility is equipped with a 20kN electro-dynamic shaker.

B. Thermal Vacuum Test

In line with the launch sequence, the thermal vacuum test will occur after the vibration test. The test will ensure that the CubeSat is capable of fulfilling all functional requirements under various temperature conditions that will be encountered during flight. It also verifies the workmanship and thermal design of the system. The thermal vacuum test will consist of 1 cycle within the non-operational temperature range and 3 cycles within the operational temperature range of the CubeSat, defined by the thermal analysis. It will also consist of dwell phases during which the temperature will be maintained at a constant value for approximately two hours. The temperature ranges for the test is defined by the thermal analysis.

Thermal vacuum testing of EIRSAT-1 will take place at ESA Education's CubeSat Support Facility. The facility is equipped with a thermal vacuum chamber with a temperature range of -60°C – +100°C and a vacuum limit of 10^{-6} mbar.

Acknowledgments

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Towards space engineering curriculum in Hungary

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***Abstract*—Although Hungarian experts made several contributions in the domain of space research and activities, there is no aerospace engineering or space engineering curriculum in Hungary. After informal and formal discussions started years ago, the Budapest University of Technology and Economics is starting the formal process of establishing the space engineering curriculum in Hungary.**

Keywords—space engineering; curriculum; Hungarian tertiary education

I. Introduction

In Hungary, it is a strategic goal to spread high-tech RDI (research-development-innovation) activities, and to develop the industrial manufacturing and service sectors capable of applying these. Hungary's full ESA membership was a significant step towards achieving the above strategic goal and offered new possibilities for the Hungarian space industry [1]. The expansion of space industry requires a significant number of well-trained professionals experienced in space technology. We would like to introduce the efforts made by the Budapest University of Technology and Economics (BME) to launch the first Hungarian space engineer training.

BME is the leader in Hungarian technical higher education and there is a long tradition of research-based education at the university. There are several application areas which are influenced by space (different technologies, satellite services, etc.) including environment and agriculture, geodesy, intelligent transport, smart cities and smart industry, telecommunication.

The university supports not only several successful personal careers but ensures remarkable contributions to the build-up of institutional and business entities of Hungarian space research and technology.

At the more than two centuries old BME, several researchers and development engineers pursued their education or work who attained world-class achievements in the area of modern space research. The education of technical and scientific fundamentals of space activity has been a considerable part of the curriculum for decades at various faculties of BME. In the past years, our students and staff members participated in the ESERO program, developed the Masat-1, the first Hungarian cubesat and currently working on the SMOG-1, the first Hungarian picosatellite, as well as participated different ESA's educational programs including REXUS/BEXUS program. The different lessons learned of these projects became educational content for the next generation of students [2]. Currently, there are about 20 courses at 4 faculties in the space domain on undergraduate and graduate level.

Although our students and staff members participate national and international space projects, it is not easy to recognize their achievements from educational point of view since aerospace engineering or space engineering curriculum does not exist in Hungary. Fortunately, several stakeholders and influencers raised the need for such a degree in the past years including the authors of this paper. Informal discussions were initialized by Hungarian Astronautical Society (MANT) in 2016, and BME started to push further by harmonizing its internal space related educational processes. According to the current national plans, establishing space engineering degree will be part the new Hungarian Space Strategy which will be adopted hopefully in this year.

In our paper, we detail the different processes which have been done so far towards establishing the aerospace engineering degree in Hungary.

II. A University with Space Heritage

A. Space researchers from the university

At the more than two centuries old Budapest University of Technology and Economics, several researchers and development engineers pursued their education or work who attained world-class achievements in the area of modern space

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research. We would like to list a few outstanding personalities from the long list below [3].

Tódor Kármán—known in the world as the father of rocket technology—obtained his mechanical engineering diploma in 1902 and lectured for years at the Royal Joseph University—entitled to issue doctoral degree in engineering—as it was called then.

Zoltán Bay, leader of the 1946 ground-breaking Moon radar experiment, established and headed the Department of Atomic Physics at the University.

Ferenc Pavlics, who received his diploma in mechanical engineering in 1950, became famous for being the development engineer of the first extra-terrestrial vehicle, the Moon rover used in the Apollo program.

Gyula Tófalvi, who in 1958 won the Grand Prize of the Brussels World Fair with his ionospheric research equipment, was among the first to obtain electrical engineering diploma at the University.

Antal Bejczy, developer of the remote-control engineering for the Mars Pathfinder, studied at the Faculty of Electrical Engineering until 1956.

Ákos Detrekői, the internationally renowned expert of geoinformatics and remote sensing, remained with the University from receiving his civil engineering diploma through his entire professional career.

The first Hungarian astronaut *Bertalan Farkas* has close ties to the University: researchers graduating from or working at BME participated the preparations of several experiments developed by Hungarians on the Salyut-6 space station (1980), and he obtained his diploma in engineering at the Faculty of Transportation Engineering of BME.

The second Hungarian to enter space, *Charles Simony*, living in the USA, also has connections to BME: his father, Károly Simonyi was an outstanding lecturer of BME Faculty of Electric Engineering and Informatics, and Charles established radio contact with BME during his space flights (2007 and 2009), and later visited the Masat-1 development team at BME.

B. Space is the final frontier

Several space equipment are related to the BME. Masat-1 is the first Hungarian cubesat, important piece of Hungarian history of science has been designed and manufactured at BME. Masat-1 became the first Hungarian made satellite that was offered the possibility to go up into space, and after the successful launch, this became Hungary's first Earth-orbiting artificial celestial body. It was a 1U cubesat (10cm*10cm*10cm), launched on February 13, 2012 and successfully operated until January 2015. The SMOG-1 picosatellite with 5cm*5cm*5cm is planned to be launch in this years. The scientific objective is to measure human electromagnetic pollution (hence the name of the satellite) in the near Earth region. Parallel to satellite developments, the operation and development of automated and remote controlled ground station capable of serving satellite contact is among the tasks.

To name one department among others, space research at the Department of Broadband Infocommunications and Electromagnetic Theory has a history with 40 years that saw equipment developed here entering space in more than 20 space missions.

C. BME Space Forum

At the Faculties of BME, numerous Departments and research groups perform space research, implementation and education activities, from theory research through the practical manufacture of diverse devices and services, to undergraduate and graduate level education. Recognizing the lucrative opportunities in harmonizing the work of the numerous individually operating research groups, a few years ago three departments undertaking space activities established the BME Space Forum and offered participation in the Forum's work (joining) for all organizations and research groups of the university.

BME Space Forum operation and management is performed by the Federated Innovation and Knowledge Centre of BME (BME EIT). President of Space Forum is Kálmán Kovács, director of BME EIT; vice president is László Bacsárdi. BME EIT was created at the Faculty of Electrical Engineering and Informatics of BME in 2009 to stimulate the research and development activity and the utilization of the research results at the Faculty and to be able to do the same at the university level [4]. BME EIT operates as a R&D service center. Its major tasks are research coordination and project management. Since 2010, BME EIT has managed 28 projects in the value of 27 M EURO and employed about 2,200 persons in 5,500 contracts. One of the most significant topics coordinated by BME EIT is the space activity (research, application and education) of BME.

There is a long tradition of research-based education in space science at BME. It supports not only several successful personal careers but ensures remarkable contributions to the build-up of institutional and business entities of Hungarian space research and technology.

Fig. 1. Before the official opening of H-SPACE 2016 conference, an international conference on research, technology and education of space. From left to right: Richard Jones (Flow Chemistry Society), János Solymosi (BHE Bonn Hungary), Ferenc Darvas (ThalesNano), Tibor Balint (Royal College of Art, now NASA JPL), Rainer Sandau (International Academy of Astrenautics), Fruzsina Tari (Hungarian Space Office), Franco Ongaro (ESA), Kálmán Kovács (BME), László Bacsárdi (BME).

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Currently, 73 Departments of the 8 Faculties encompass the research & education activities of BME. From among these, 13 Departments of 4 Faculties are members the Space Forum. Participants of Space Forum joined voluntarily. It is their common objective that the various space activities performed at BME should not be dissipated, but all activities in this field should be coordinated along a jointly worked out strategy.

Space Forum represents its member organizations in a uniform manner towards BME's current and future partners, and initiates cooperation that may significantly contribute to the more efficient utilization of the university's research and educational capacities.

III. On the way to the Hungarian space engineering curriculum

In the past years, the different Hungarian stakeholders have agreed in the need of the space oriented tertiary education. Space science and space engineering are in the main focus of the national strategy. As an engineering university, we would like to focus on the space engineering curriculum.

A. *H-SPACE conference series*

The H-SPACE conference series refers to our series of "International Conference on Research, Technology and Education of Space" [5-10]. The event is organized by BME EIT – in cooperation with the Hungarian Astronautical Society (MANT). The organization of the conference series started in 2015, at a time of growing opportunities arising from ESA recently granting membership to Hungary and the need for a joint presentation of space activities pursued at BME. The selection of the date of the event pays tribute to the successful deployment to orbit and mission of the first Hungarian satellite, the Masat-1, which has been launched on February 13, 2012, so the conference is organized in every year in February. In 2016, the first European Space Generation Workshop of Space Generation Advisory Council has been organized as a joint event of the H-SPACE 2016 conference.

The education session of the H-SPACE conference series has a special focus on secondary and tertiary education. Fig.1. was taken before the official opening of the H-SPACE 2016 conference.

Fig. 2. Participants of the roundtable discusisons in 2016, organized by the Hungarian Astronautical Society with title: "Space engineering in Hungary: opportunities and challenges".

B. *Rountable discussion*

The Hungarian Astronautical Society (MANT) is the oldest Hungarian non-profit space association, founded in 1956. This society gathers Hungarian space researchers, users of space technology and everyone who is interested in the interdisciplinary and state-of-the-art uses and research of outer space. The aim of the association is to raise public awareness about space exploration and uses. It also provides opportunity for space enthusiasts to meet, exchange ideas and work together [11]. The society organizes several programs for the audience during the year including trips to space related institutes, student competitions and talks given by its members.

On October 21, 2016, the Hungarian Astronautical Society organized its annual Day of the Hungarian Space Research event. This is a half day event dedicated to the latest Hungarian and international research activities. In 2016, the event started with a 90-min-long workshop with Hungarian stakeholders about the space engineering: "Space engineering in Hungary: opportunities and challenges". The roundtable discussions with representatives of government, industry, universities, academia and space organization was followed by a direct questions and answers from the audience.

Participants of the roundtable discussions were the following (see Fig. 2.): Pál Bárczy *(Admatis Ltd, HUNSPACE cluster)*, Dániel Bényei *(Space Generation Advisory Council)*, Ákos Kereszturi *(Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences)*, Kálmán Kovács

Fig. 3. Group photo of the participants of the 2nd Symposium on Space Educational Activities in 2018 which was hosted by Budapest University of Technology and Economics and the Hungarian Astronautical Society in 2018 in Budapest, Hungary.

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(Budapest University of Technology and Economics), János Lichtenberger *(Eötvös Loránd University)*, Ervin Rácz *(Óbuda University),* János Solymosi *(BHE Bonn Hungary, HATP cluster)*, Fruzsina Tari *(Hungarian Space Office)*, László Bacsárdi *(Hungarian Astronautical Society)*.

Following the roundtable discussions, BME and MANT started to provide more space for tertiary education activities in their international H-SPACE conference series. In early 2017, they decided to submit a proposal for hosting ESA's 2nd Symposium on Space Educational Activities. MANT decided to continue the discussions of the roundtable discussions during its annual Space Academy series either in 2017 or in 2018.

C. SSEA 2018

In April 2018, BME and MANT organized the 2nd Symposium on Space Educational Activities [12]. It followed the first symposium held in Padova, Italy in 2015, and continued to be an excellent forum for university students, professors and professionals from all over Europe to present and discuss their educational space-related projects and programs. We had a keynote presentation, six plenary lectures including an astronaut talk, more than 80 oral and poster presentations. Besides providing an opportunity for dissemination of information about educational and research activities, the symposium allowed sharing experience among students and young professionals from different countries and networking with international researchers. The symposium was held on April 11-13, 2018 at the premises of BME. All of our participants were invited to the Welcome reception on Wednesday in Trófea restaurant, a special Yuri's night party on Thursday in the Schönherz Dormitory and a Gala dinner on Friday evening with a 3-hour-long cruise on River Danube on board of the Európa ship. The symposium was organized by BME EIT in cooperation with MANT. The event was carried out under the supervision of European Space Agency's Education Office. We had 206 registered participants from 23 countries including 111 university students, 41 young professional and 54 professional participants. Fig.3. shows a group photo of the participants.

After the symposium, several discussions have started in the country about the importance of the space oriented tertiary education. These discussions were formalized during the 4th Hungarian Space Academy, which was organized in Aug 2018.

D. Space Academy 2018

MANT started to organize its annual Hungarian Space Camp series for secondary school students in 1994. [13] As the continuation of the successful series, MANT decided to organize an event for university students and young professionals in 2014. Following the success of the one day event, together with the Space Generation Advisory Council (SGAC), MANT organizes a four-day summer event in August for Hungarian university students and young professionals between 18 and 35 years, named MANT Space Academy [14]. Every Space Academy has a specific topic. During the program, the participants listen lectures about Hungarian space projects. They work in small groups to create a detailed proposal about the chosen topic by the end of the event. Based on the final proposal, which include the benefits of the projects for Hungary, the participants can form teams and start working on the project during the next academy year [15]. In 2018, the event was organized on Aug 2-5 in Gödöllő, Hungary, and the space education was in the main focus. The participants, as illustrated in Fig.4., were discussing about the different educational possibilities. One of their final recommendation was the urgent implementation need for a master course in space engineering. Following the Space Academy, MANT has established a permanent working group on tertiary space education. The members of the working group started to collect information about different Hungarian tertiary education initiatives and subject.

E. Intializing the establisment of space engineering curriculum

The education of technical and scientific fundamentals of space activity has been part of the curriculum for decades at various Faculties of BME. Selected topics include satellite positioning (BSc), Satellite geodesy (MSc), Global navigation satellite systems (MSc), Environment and remote sensing (MSc), Optical systems design (BSc), , Space dynamics (BSc/MSc), Special propulsion, rockets (BSc), Aerodynamics and dynamics of hypersonic flight (MSc), Space technology theory and practice (BSc/MSc), Telecommunications, Antennas and propagation, Critical embedded systems, High fidelity systems, Embedded systems, Cyberphysical systems, Quantum communication and many more.

In 2019, BME initialized a process which will lead to the establishment of the space engineering MSc curriculum in the country. If the curriculum is established, every Hungarian university which has the necessary competences can start a space engineering program for their students. Currently, we plan a two-year Master course which will cover the most important aspects of space engineering. The curriculum will consist of 120 credits, from which 30 credits will assign to Diploma thesis. The remaining 90 credits will be distributed among different subjects. Calculating with 5 credits per subject, it will allow 18 subjects for the curriculum. However, if the average credits is only 4 credit per subject, the space engineering curriculum can have 22 subjects.

Fig. 4. Group photo of the participants of Hungarian Space Academy 2018. The event was organized on Aug 2-5, 2018 in Gödöllő, Hungary. The participants were university students and young professionals (age 18-35). The main discussion topic of the event was the tertiary space education. After the event, the Hungarian Astroautical Society has established its permanent Space Tertiary Education Working Group.

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IV. Conclusion

Although Hungary is not a big country, there are more than 40 organizations (companies, research institutes, universities) which are part of the Hungarian space sector. Every Hungarian stakeholders agree in the importance of space oriented tertiary education. We believe that a space engineering master curriculum could utilities the Hungarian competences and offer continuous support to the workforce development in the space sector.

Acknowledgment

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Assessing the Impact of Space School UK

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Space School UK (SSUK) is a series of summer residential programmes for secondary school aged students, held at the University of Leicester over 3 weeks each year. Each programme involves space-related activities run by a team of mentors - currently including university students, graduates, teachers and young professionals associated with the space sector - all of whom attended SSUK as students themselves. It includes the 6-day Space School UK and the 8-day Senior Space School UK (collectively SSUK) which are for 13–15 and 16–18 year olds respectively.

This paper seeks to evaluate and present the benefits of SSUK to individuals who participate in the programme, organisations involved in the running of SSUK, and to highlight and promote these benefits to the wider UK and global space community.

We also address which facets of SSUK make for such an engaging and encouraging experience for the students, that are missing from students' traditional education. We seek to show how SSUK acts as an excellent example of how to bridge the gap between secondary and tertiary space education. Through an analysis of our alumni survey results, we show that attending SSUK has a significant impact on career choices and prepares students for Higher Education, regardless of background. Some groups, such as women, and those from non-selective schools, reported a higher impact in some of these areas than others. Metrics such as skills learned, goals achieved, alongside knowledge of careers and Higher Education possibilities are discussed for various demographics.

Keywords—Space, Education, Summer Camp, Higher Education, Careers

I. Introduction

Space School UK and Senior Space School UK (collectively SSUK) are six- and eight-day fee-paying, non-selective, residential summer schools at the University of Leicester (UoL) for students aged 13–15 and 16–18 respectively. Industry sponsorship and involvement in SSUK has varied in the past, providing scholarship places to widen participation of the summer school. Most recently, approximately 20 students each year have been fully funded in this way. The schools are run by a team of mentors, all of whom are now alumni and study for/have studied a space-related degree.

The aims of SSUK are to educate and inspire young people through astronomy and space science, preparing students for space careers and giving them a taste of university life. Students participate in activities similar to those they would experience as STEM undergraduates, e.g. lectures, small group practical experiments and problem-solving workshops. Students also learn other space-related skills such as scuba diving, which gives them an experience of astronaut training and an understanding of the effects of microgravity on the human body. Students stay in university accommodation, except for one night of camping to observe the night sky, coinciding with the Perseids meteor shower for Senior Space School UK. Students also get hands on experience of practical astronomy through the use of UoL's ground-based telescopes.

Space School UK began in 1989 at Sevenoaks School, Kent. In 1990 it moved to Brunel University, then moved to its current home at UoL in 2000. To celebrate its 30-year anniversary, its alumni community were asked to complete an anonymous online survey regarding its impact. The authors used social media to contact SSUK alumni to ask them about their experience, their motivations for attending, and the impact on their lives and careers. Alumni were invited to complete the survey via posts on social media: Twitter, Facebook groups, and the SSUK Facebook page. These platforms have a combined ~2,500 followers, some of which will overlap and not all of whom are alumni (e.g. parents). The survey was available online for 2 weeks over July 2019. 144 people completed the survey (~6% of the estimated total alumni population of ~ 2400). When asked to rate whether alumni would recommend SSUK to young people interested in space, the average score was 4.96 out of 5, indicating that SSUK is regarded as a highly positive and worthwhile experience. This paper provides a detailed analysis of answers to selected questions from the survey, related to the goals outlined in Section II.A below.

II. Methods

A. Survey Goals

Questions were chosen to determine how effective SSUK is at addressing the following goals:

1. Prepare students for the study of space-related subjects at university;
2. Inspire students to work and study space-related subjects beyond school and higher education;
3. Improve the knowledge, skills and understanding of students in space-related subjects.

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The survey aimed to determine if there were trends for any particular demographics (e.g. age, gender, educational background, highest level of education) and how they felt SSUK addressed the goals listed above.

B. Question Styles

Demographic questions were asked with multiple choice or check box answers. Respondents were also asked several questions about the extent to which (on a scale of 1-5, where 1 is the lowest and 5 is the highest) they felt SSUK prepared them for higher education and their careers, particularly in STEM/space-related disciplines.

C. Data Analysis

Responses were coded by the authors in order to simplify data sets when free-form answers were given as an option, to allow for ease of trend identification. Where there were lower numbers of particular groups (e.g. some degree subjects), these were grouped together. An example of this was for those who identified their studies as either medicine, chemistry, biology, or earth science and geography-related, these subjects were coded as 'Other STEMM' (Science Technology Engineering Maths and Medicine). Pivot tables were then used to determine any trends in the 1-5 scale responses by different groups (such as subject studied, gender etc.). For any situation in which an "average score" for one of these 1-5 questions is being discussed, it is the population-weighted mean of that category.

In order to investigate the average scores given by different groups for survey questions, a standard error, α, was calculated, using:

$$\alpha = \frac{\sigma}{\sqrt{N}}$$

whereby σ is the standard deviation in the dataset and N is the population size of that dataset.

III. Results and Discussion

A. Respondent Demographics

Of the 144 respondents, 55% were female and 45% were male. The historic gender balance of SSUK is approximately 40% female and 60% male.

Before 2007, there was no separate Space School UK and Senior Space School UK, only a single school for all students aged 1318. Only 14% of our respondents attended SSUK prior to its separation into two schools in 2007. For the last 4 years, Senior Space School UK's popularity grew such that there needed to be two senior schools each year, so the number of recent, younger, alumni is larger. Over half (52%) of respondents attended SSUK recently (2014-2018 inclusive) at least once and 71% of respondents had attended between 2009 and 2018. The young age of respondents is reflected in the highest level of education completed, with 36% of respondents citing A-Level or equivalent as their highest level of education, followed by Masters (30%), and Bachelors (19%). More female respondents have PhDs than male respondents (12.5% to 7.6%) whilst more men have Masters (33% to 26%).

Two thirds (66%) of attendees attended a comprehensive school or state-funded grammar school, and one third (31.7%) attended a private day or boarding school. The remaining 2.2% were home-schooled. As this portion was so low, answers from this group were omitted from our schooling-based analyses, due to the large associated uncertainty. 40% of respondents attended SSUK once, whilst 60% reported attending SSUK twice or more. 19.2% of respondents work, or have previously worked, as a mentor at SSUK (see limitations outlined in Section IV at the end of this manuscript).

B. Influence on Higher Education Choices

1) Overview

In this section, we explore the impact that attending SSUK had on the Higher Education (HE) paths of respondents. We follow this by discussing a breakdown of responses by qualification, gender and school background.

For the question 'If you went to/are at university/hold an offer, which of the following best describes the degree(s) you studied/intend to?', respondents could pick all that applied, the most common subject was physics-related with 61%, followed by 11% for engineering-related and 8% for maths-related (see Figure 1). Although these subjects are the most common routes for those enthusiastic about space, it is also encouraging that we find other subjects prevalent, with 5% studying Arts and Humanities and 4% studying Medicine and/or Veterinary Science. This implies that SSUK can be an enjoyable experience for those who are interested in space regardless of which degree they later pursue.

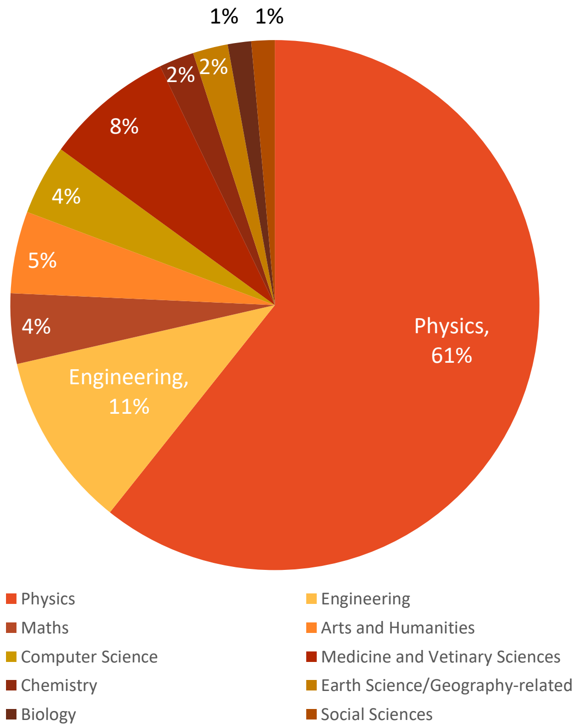

Fig. 1. The subjects studied by SSUK alumni survey respondents, when asked "If you went to/are at university/hold an offer, which of the following best describes the degree(s) you studied/intend to? (tick all that apply)"

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4.1% of the UK student population in 2017/18 studied a physical science degree according to [1], which significantly contrasts with our respondents (61%). As well as physics being the most popular subject amongst our survey respondents, Figure 2 shows that those who studied Physics found that SSUK encouraged them to study it, more than any other subject. With an average score of 4.4 ± 0.1 for this question**,** it is evident that SSUK has strongly encouraged many students to pursue a physics-related degree.

Since 2000 the UoL School of Physics and Astronomy has hosted SSUK, also a factor in encouraging students to consider physics-related degrees. 89% of those surveyed had attended SSUK at the UoL. We also find that UoL is the most common university destination of respondents, at 13%. Furthermore, of the mentors (staff who provide both pastoral and educational support to students during the residential) who completed the survey, 79% have completed or are currently enrolled in a physics-related degree, and 30% of them have attended UoL. 52% of respondents felt that the mentors encouraged/prepared them for their studies/careers, which indicates that the alumni's choices are likely to have been influenced by both the subjects studied and university destinations of their mentors.

It is also encouraging to note that, regardless of degree subject, there was a very positive response to 'What impact did SSUK have on your opinions/plans of entering HE (higher education)?' and 'To what extent did Space School prepare you for HE?' (see Figure 2). This demonstrates that SSUK is a valuable experience for attendees to gain an insight into HE, regardless of whether they chose to study a STEM related degree. Furthermore, SSUK is successful in helping to bridge the gap between school and HE.

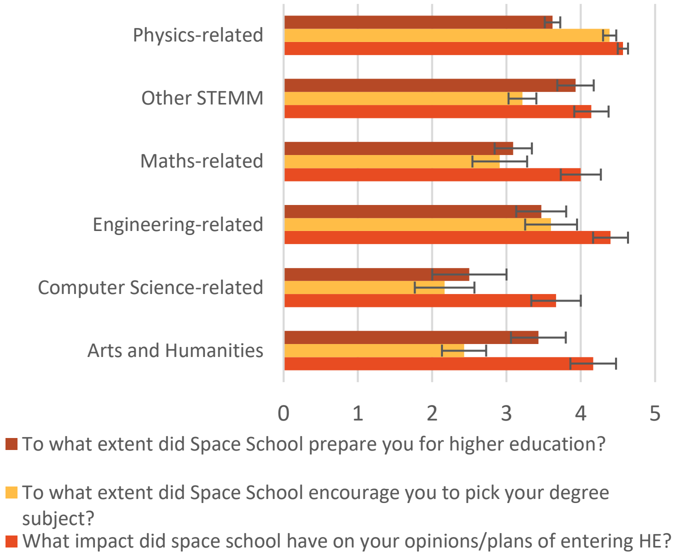

Fig. 2. Average scores to answers to HE questions in the SSUK alumni survey displayed by degree subject studied

We do, however, note that those who study computer science rated all three questions the lowest compared to other degree types. In the most recent years of SSUK, a programming workshop has been introduced, so we hope that this will have a positive impact on future alumni interested in computer science, particularly as this is such an important discipline in the space sector. The lack of mentors who study computer science (7%) is also likely to have contributed to this.

When we look at how respondents with different levels of qualifications answered the question 'To what extent did SSUK encourage you to pick your degree subject?, we find that those with PhDs gave an average score of 4.3 ± 0.2, compared to 3.9 ± 0.2 for those with Master's degrees, 3.6 ± 0.3 for those with Bachelor's degrees and 3.9 ± 0.1 for those with A-level's or equivalent. Those who felt most influenced by SSUK to pick their degree subjects were those that went on to gain a PhD, indicating that SSUK has a lasting impact on those that felt strongly inspired by attending.

2) Investigating influence on HE by gender

When we look at which degree subjects female and male respondents studied, study, or intend to study, we find that pure physics-related degrees were more popular in women than men (43% to 39%), whilst more men chose engineering related degrees (16% to 4%). It is interesting to find that a higher proportion of female survey respondents studied pure physics than male respondents, given that, according to [1], 58% of physical science undergraduate students are male. Furthermore, grouping together all those who studied physics-related degrees (thereby including those who studied physics and other subjects) we find that 61% of female respondents studied physics, compared to 57% of male respondents. SSUK appears to have a positive effect on female students in encouraging them to study physics at university. This is supported by responses from female respondents who study physics giving an average rating of 4.5 ± 0.1 to the question ' To what extent did SSUK encourage you to pick your degree subject?' and 4.6 ± 0.1 to 'What impact did space school have on your opinions/plans of entering HE?'.

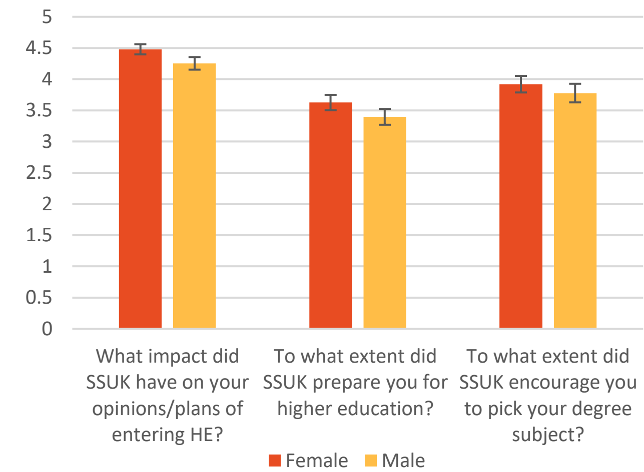

Fig. 3. Average scores of answers to HE questions in the SSUK alumni survey displayed by gender

When we look at the impact of SSUK on HE for male and female populations as a whole, we find some slight differences. Figure 3 demonstrates the average score for men and women for three HE-related questions. Although the average scores between male and female respondents agree within error, we do observe a trend, with female respondents answering more positively, on average, to all questions. This demonstrates that

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SSUK holds a unique atmosphere of support and encouragement for girls into HE. One reason for this could be that 50% of mentors who responded are women, and 18% of female respondents answered 'mentors' to the question 'Which of these categories would you say has helped you most with your studies/career?', compared to 13% of male respondents. This highlights the importance of having female role models for girls, and how SSUK has provided this for many female alumni. This is explored further in part 4 of this Section.

3) Investigating influence on HE by schooling type

We can see from Figure 4 that there is variation in the impact SSUK had on HE choices with the type of schooling the respondents had.

For this study, those who answered that they either attended a private school, boarding school or state grammar school were grouped as having attended mostly selective schools. The authors recognise that not all boarding and private schools are selective with their intake. The scores for selective and non-selective schooling are largely consistent with one another, within error, indicating that SSUK adds value regarding HE choices, regardless of school background. However, the average scores for non-selective schooling are a little higher on average for all questions, indicating that those who attended comprehensive schools felt that they benefited the most from SSUK. The authors therefore encourage industry representatives (such as Lockheed Martin UK, Virgin Orbit and the Air League) to continue to sponsor places at SSUK under a remit of widening participation, to ensure those from lower socio-economic backgrounds can also access and benefit from SSUK.

Fig. 4. Answers to HE questions in the SSUK alumni survey displayed by schooling type

C. *Influence on Career Choices*

1) Overview

The longevity of SSUK over the past 30 years enables this study to compare and review how alumni's attendance at SSUK has affected their career path. The opinions and insights of those who are in their mid-late careers are useful for not only the SSUK organisers but also for its students and the wider space sector. As evidenced by this report and below data, SSUK is of great importance for assisting alumni in achieving their career goals.

We find that 50% of survey respondents who have studied engineering stated they intended to work in the space sector, compared to just over 35% of physics-related graduates and students. An additional 21% of engineers currently or have previously worked in space. This is a largely positive results given the UK Space Agency's plan for the UK industry to be worth £30 billion by 2030 [4], whereby a larger technical workforce is required. It would be interesting for future studies to determine why 29% of our engineering students and graduates have chosen to pursue a career outside of space.

We find that 41% of the physics-related respondents have worked in the space sector, now or in the past, compared to only 21% of engineering respondents. Also, of the computer-science and maths-related sample population, a similar proportion of each had at some point worked in the space sector as the proportion of their samples that stated they were intending on one day working in space (17% and 18% respectively). This indicates that SSUK alumni with STEM backgrounds are well represented in the space sector.

The statistics for what area of the space sector respondents work or worked in (only answered by those who do already work in space) show a strong preference for academia, education and research - accounting for over 46% of the total respondents in the space sector, whilst 26% of our alumni working in the space sector work in industry. 16% of respondents identified as working in space education, 25% of whom are mentors.

2) Influence on Career Choices by Gender

From Figure 5 we can see that of those alumni currently or previously in the space workforce, the gender split is roughly even. We also find that 25% of male respondents currently work in the space sector compared to 22% of female respondents. In addition, 8% of male respondents stated they had previously worked in the space sector compared to 6% of female respondents. These figures show that, of our alumni in the space sector, women make up 46%. This contrasts, for example, with the UK STEM sector which is 22% women, suggesting that SSUK has a positive influence on gender balance in the UK space sector [2].

Fig. 5. Answers to the question "Do you currently, or have you in the past, worked in the space sector?" displayed by gender

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There is a higher proportion of male respondents intending to work in the space sector than female respondents — 38% and 24% respectively. More than double the number of female respondents than male respondents stated they intended to start a career in STEM however, but not necessarily one in the space sector (nearly 23% of female respondents defined themselves as this vs 11% of male respondents). We would therefore expect a greater representation of female SSUK alumni in STEM fields in the future.

When asked about SSUK's influence on them pursuing a space or STEM career the average female respondents' score is higher than for male respondents (see Figure 6). When separated into their HE subject-related groups this effect is also seen, with each subject group's female respondents registering a higher average than their male counterparts, apart from in maths-related subject (see Figure 7). This reinforces the previous suggestion that SSUK has a greater influence on female attendees.

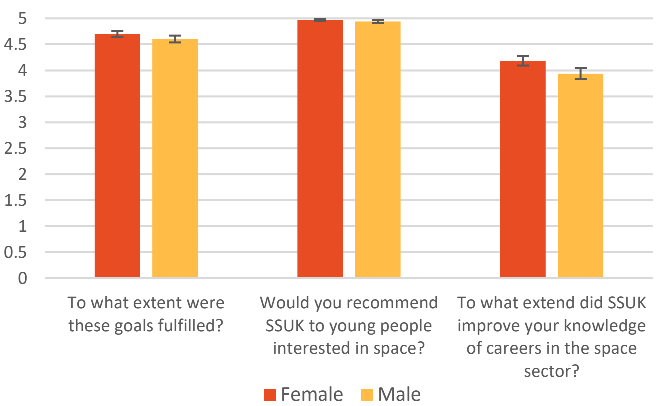

Fig. 6. Average scores of the effect of SSUK on space careers/goals displayed by gender

3) *Career history and overlap between space and STEM*

Responses to our survey questions on work history suggest that SSUK alumni are likely to pursue a career in STEM at some point, with 53% of respondents currently working in STEM or having done so in the past, and an additional 27% intending to do so in the future. Furthermore, all SSUK alumni working in the space sector identify themselves as working in STEM (Figure 8). An additional 25% who have previously worked in the space sector also identified themselves as having worked in STEM. Of those intending to work in STEM in the future, 69% also intend to work in space and 33% of those who have previously worked in STEM still intend to work in space in the future. Overall 60% of respondent alumni stated they intended to or had at some point worked in the space sector.

Figure 8 also seems to indicate that whilst SSUK alumni tend to go into STEM roles within the space sector (and are arguably well supported and encouraged to do so by SSUK), very few of them seem interested in pursuing space from a non-STEM career perspective. As the skills section of this report shows, SSUK is extremely beneficial for those taking up roles in the space sector (as self-professed by respondents), and particularly so for groups that traditionally face added barriers in STEM careers such as women and non-selectively schooled students.

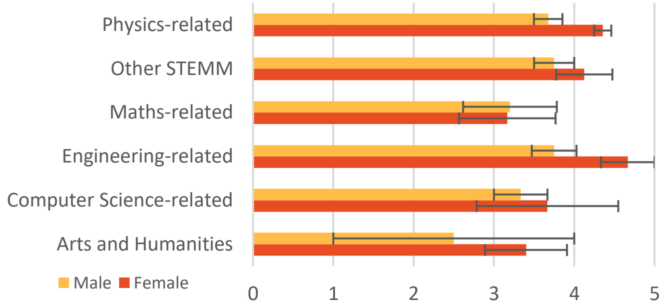

Fig. 7. Average score of answers to 'To what extent did Space School influence you to consider a STEM career?' displayed by gender

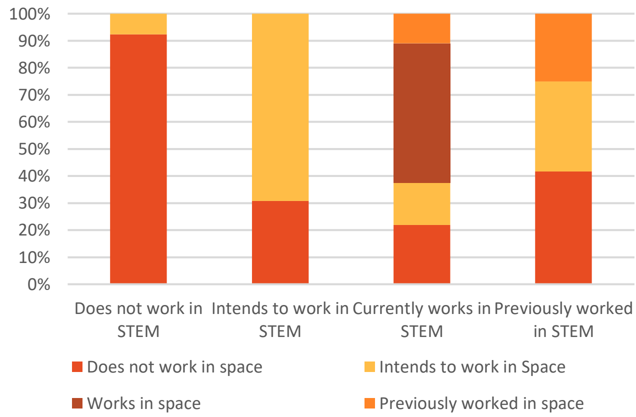

Fig. 8. Answers to "Do you currently, or have you in the past, worked in the space sector?" displayed with answers to "Do you currently, or have you in the past, worked in STEM?"

4) *Investigating influences on career choices by schooling*

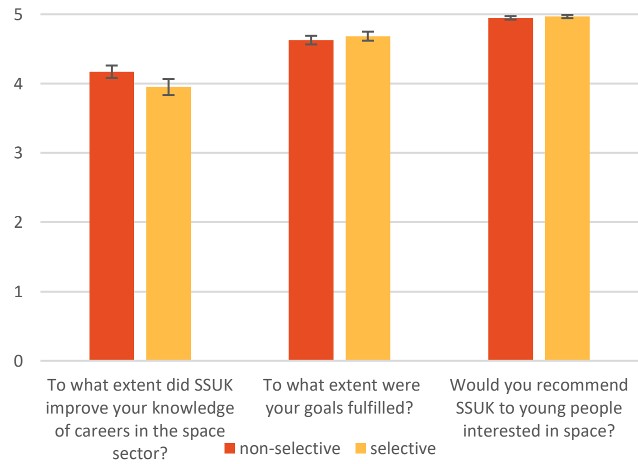

Fig. 9. Average scores to questions on career choices and goals in attending SSUK displayed by schooling type (selective schooling vs non-selective, ie state maintained comprehensive schooling.

When the average scores from pupils from non-selective schooling are compared to those from selective schooling (Figure 9) we can see that both alumni groups would recommend SSUK highly (4.95 ± 0.1 vs 4.97 ± 0.1 respectively). Non-selectively schooled students reported learning more about careers in the space industry than selectively schooled alumni,

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although selectively schooled alumni polled a slightly higher mean of having their original goals for attending SSUK fulfilled (although they do agree within error). 78% of total respondents answered either a 4 or 5 for the question regarding the improvement of knowledge of space careers - a mean of 4.08 ± 0.1 across all responding alumni.

5) Outreach and Education

We find that 75% of respondents who work, or have previously worked, in STEM said that SSUK encouraged them to participate in outreach/education for future generations, whilst a further 15% of those in STEM said it may have done. For those who work/have previously worked in space, the response was largely the same. It is encouraging to also find that 39% of respondents not working in STEM also reported that SSUK encouraged them to participate in outreach/education. Especially as a further 19% of this group said that SSUK may have encouraged them to do so.

However, these data will be skewed, since 28% of those who said that SSUK encouraged them to do outreach/education are mentors. We find that the mentors were the group that rated this question the highest, with 89% of them answering yes to 'Did Space School encourage you to participate in Outreach/Education for Future Generations', which indicates that SSUK encouraged this group enough to pursue outreach/education by becoming a mentor.

D. Impact of SSUK on skills development

As well as their views on HE and careers, alumni were also asked questions about their goals of attending SSUK and the skills they felt they took away from it.

When asked what their goals were in attending SSUK, where they could tick all that apply, the main reasons respondents cited were to learn more about space/astronomy (93%), meet like-minded people (68%) and to learn more about possible space careers (51%). When asked what skills they learnt by attending SSUK, knowledge and understanding of space was highest (87%), followed by social confidence (83%) and teamwork (71%).

We find that SSUK has a strong positive effect on young people's 'soft skills' and that these were cited as being the most beneficial when asked which category has helped them the most with your studies/career. Socialising/building a space network was cited the most, at almost 25% (see Figure 10). This percentage is higher for female respondents than male respondents (see Figure 11), suggesting the positive influence of SSUK on gender balance, as, for example, the gender balance in SSUK (~40% female historically) is higher than the gender balance of A-level physics (~20 %, according to [3]). This higher representation of women may contribute towards the higher scores given by female alumni in this survey. This result is important, as it clearly demonstrates the extra value that providing a positive environment and role models for girls is key in encouraging them to pursue careers in STEM and the space sector, as many alumni have done.

Furthermore, female respondents reported that SSUK increased their skills in teamwork and problem solving more than male respondents, whilst male respondents cited increased skills in communication, organization, practical and technical skills over female respondents.

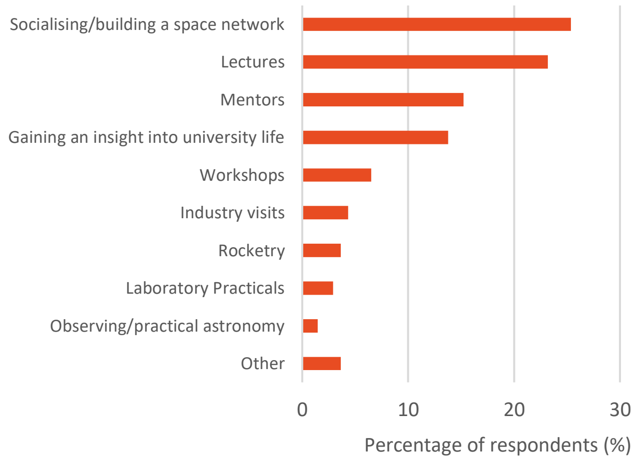

Fig. 10. Most common answers to 'Which of these categories would you say has helped you most with your studies/career?

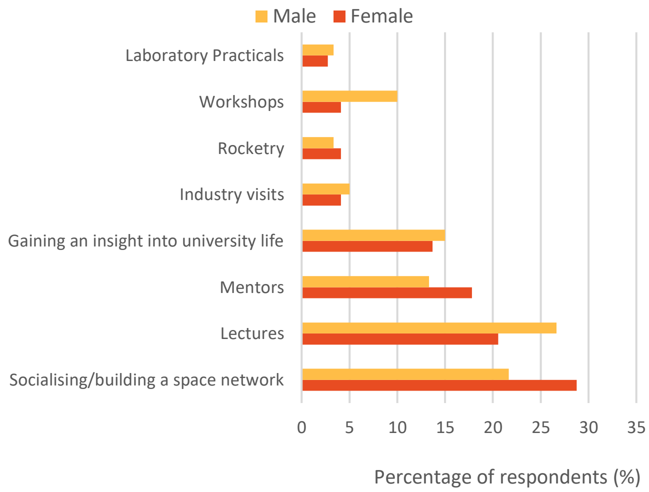

Fig. 11. Percentage of male and female respondents' answers to 'Which of these categories would you say has helped you most with your studies/career?'

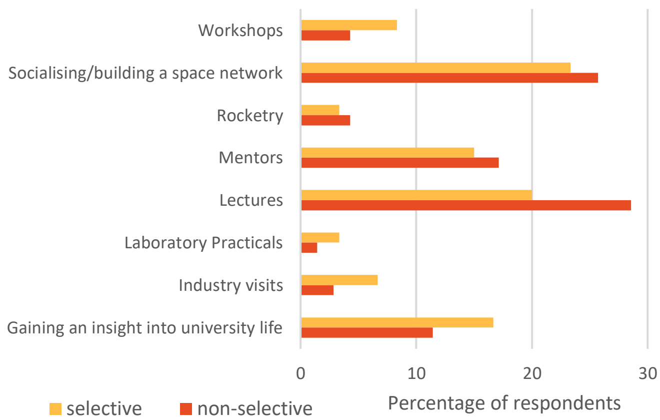

Fig. 12. Percentage of selectively and non-selectively schooled respondents' answers to 'Which of these categories would you say has helped you most with your studies/career?'

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SSUK not only improves confidence and teamworking skills, but 44% of those who have gone on to work in the space sector have identified that socialising and building a space network was the most useful aspect of the summer school.

When these skills-based questions were grouped by schooling, Figure 12 was produced showing alumni's self-reported most beneficial aspect of SSUK to their career. Some notable points from this are that selectively schooled students found workshops, industry visits and getting an insight into university life to be the most useful aspects of SSUK. Conversely, non-selectively schooled students found the lectures significantly more useful, and mentors slightly more so.

IV. Limitations of this study

Due to time constraints, the survey was only available for two weeks via social media, reducing the potential reach. Due to GDPR constraints, i.e. lack of alumni email addresses, social media and word of mouth were the main forms of sharing the survey. Although SSUK social media groups have existed since 2007, members are predominantly more recent alumni, younger people, and current mentors, so were more likely to have completed the survey over people who attended SSUK longer ago. Over half (52%) of respondents attended SSUK recently (2014-2018 inclusive) at least once, and 71% of respondents had attended between 2009 and 2018. This therefore skews the dataset away from those in their mid-late careers.

Of those aware and with access to the survey, those who are more engaged with the SSUK community and space in general are more likely to have been motivated to complete the survey than those less enthused. This will systematically skew some data. 40% of respondents attended SSUK once, whilst 60% reported attending SSUK twice or more. 19% of respondents work, or have previously worked, as a mentor at SSUK. These mentors are especially likely to perceive SSUK in a more positive light and with a greater influence on their lives, as are those that came multiple times as they are presumed to have enjoyed it enough to attend again.

Many alumni may have already had the resources, skills, connections and interest to pursue HE and/or a career without attending SSUK. However, this work shows SSUK has still reinforced interest in space and broadened students' views of the space sector and career choices in nearly all respondent cases.

V. Conclusions

SSUK teaches skills and provides opportunities that many respondents feel were critical for them to study and establish careers within the STEM and space industry. Some groups reported stronger than average positive influences from SSUK; these include women and students from non-selective school backgrounds. We find this is particularly the case for alumni from these groups entering HE, for example, both the female and non-selectively schooled alumni's average score for 'What impact did SSUK have on your opinions/plans of entering HE' was 4.5, higher than their male and selectively schooled counterparts (4.2 and 4.3 respectively).

The survey finds that SSUK primarily increased knowledge and understanding of space, but also increases students 'soft skills', such as teamwork and communication. SSUK adds value, regardless of background, to aspirations for careers and higher education, building technical and soft skills.

We find that a large proportion of respondents have at some point worked in STEM (53%) and 30% have also worked in the space sector, meaning that alumni are well represented in these areas in the UK. Another 27% of respondents indicate they have the intention to work in STEM in the future, with 69% of these also intending to join the space sector. Furthermore, SSUK tends to encourage alumni to participate in outreach/education themselves, which is an important part of continuing SSUK's legacy.

As a result of this survey, the authors encourage our likeminded colleagues to provide networking opportunities in space for young people. 43.8% of respondents who have gone on to work in the space sector have identified that socialising and building a space network was the most useful aspect of the summer school. SSUK generates long lasting impacts for its participants, particularly women, through creating and maintaining a space network from a young age.

The UK Space Agency's goal for the UK to make up 10% of the global space sector by 2030 will only be reached by increasing the size of the workforce [4]. SSUK inspires young people to join the sector through giving insights into work and study in the field. Through this work we have shown that SSUK is in a unique position to provide a space careers pipeline and network in the UK.

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On the Impact and Needs of Various Audience Groups from Space Analogue Outreach and Education Programmes

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1 Space School UK, 2 Space Generation Advisory Council, 3 Florida Institute of Technology, 4 International Emerging Space Leaders, 5 International Space University SSP 2014

***Abstract*— The Mars Desert Research Base (MDRS) is a Mars analogue simulation facility in the Utah desert operated by the non-profit organisation, The Mars Society. The authors took part in Mission 205 to MDRS as part of the International Emerging Space Leaders (IESL) Crew in February 2019. The objectives included leadership development, surface navigation techniques, sample collection, astronomy and outreach. Some of Crew 205 had strong backgrounds in science communication and investigated outreach methods and protocols on "The Red Planet".**

Some of the issues affecting current ISS also affect space analogue outreach programmes - limited data rates and bandwidth, physical remoteness, crew time/willingness, time difference/lag and other simulation conditions. These limitations can hamper the reach and effectiveness of outreach campaigns and are only likely to get worse during predicted future exploration missions.

Other differences exist between earth-based analogues and future Mars missions that can affect the receiving audience's engagement - in particular the perceived level of risk that the crew is under from environmental factors (such as weather or atmosphere), technical malfunction, isolation or the level of support the crew can receive if required. However, despite this, much can be gained by using analogue missions for effective space outreach.

This paper assesses the facets that can be best exploited to engage educators and students using the British Science Association Audience Model, without degrading the fidelity or validity of the simulation. It proposes improvements in pre-mission outreach planning at MDRS that may be applicable for other analogue missions as well.

Keywords—outreach; space; analogue; communications; MDRS.

I. INTRODUCTION

The inspiration for this paper came from the authors' time serving on Crew 205 at the Mars Desert Research Station (MDRS) in Utah, USA. Crews experience two weeks of simulated Martian living, including the inability to leave habitat buildings without EVA suits, and limited supply/type of food and drink [1]. Crew 205 conducted experiments on leadership, psychology, navigation, ISRU plant growth experiments and geologic classification of substrates - alongside outreach activities – as it seemed an excellent opportunity to show that exciting space research can be done here on Earth, whilst under communication limitations "analogous" to those of ISS or interplanetary locations [2].

Most partner organisations receiving outreach were secured by the personal and professional relationships of Crew 205 members, with outreach "products" being shared through digital media both during and after the mission, including daily photo updates, journalism reports, and the posting of crew bios - all encouraged by the Mars Society. Crew 205 also posted "shout-out" photos (posed photos with a sign, prop or caption mentioning a partner organisation or specific person), encouraged Facebook audience interactions through photos and posting comments, photos with the Crew's puppet mascot and recorded interviews/short lessons on Mars exploration topics. The crew also utilised Facebook, Twitter and Instagram pages, each shared by crew members and/or universities to attract an audience prior to the mission's onset.

The public Facebook page generally received the most audience attention, with the largest following (n>400) and significant crew/follower interaction on posted content, usually with good commitment (comment, questions and compliments on posts as opposed to just "likes") [3].

One problem Crew 205 faced was that while missions to space or high-profile analogues such as Mars 500, Biosphere 2, HI-SEAS and Antarctic Bases can generate lots of public interest, small bases like MDRS appear to be lesser known. Results showed that most social media followers were family, university friends or colleagues (i.e. people who already knew about the mission or were studying/working in STEM or space-related fields). The same passions that drive STEM professionals make them an endemic audience demographic, therefore it is imperative for analogue participants to consider other audiences, particularly amongst educational bodies.

Currently, unless someone knows a crew member or is within their reach on social media, they are unlikely to be aware

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of missions or outreach at analogues like MDRS, unless they are researching similar topics on the internet. It is often overlooked that students and graduates at MDRS (and other analogues) make excellent science communicators, but currently face difficulties in sharing their science with the broader public and efficiently utilising their mission for outreach.

Many studies have shown that school children and teachers are excellent target audiences for STEM and space outreach [4][5]. They are an impressionable audience; able to appreciate real-world applications of space technology and the relevance it has in their societies. They would also be particularly inspired by how young people (most MDRS crews are HE or postgraduate age) can get involved and be a vital part of research into spaceflight and human life on other worlds.

Young people are an important audience for space / STEM outreach – and space exploration has the added benefit of being an exciting subject to teach curriculum STEM in an engaging manner. Both the UK Space Agency and ESA Education have repeatedly stated their awareness and commitment to using space as a tool to better teach STEM subjects and ensure a continued and growing supply to the space and STEM workforce [5][6].

Safeguarding laws (preventing unsupervised contact between pupils and crew members) ensure that all parties are protected, however require extra steps to be taken before outreach can happen in schools [7]. Crews, for instance, should not be encouraging children in schools to follow their own or even all-crew/mission specific social media profiles. Crews can also lack experience on topics that are suitable for school education and audience opinion on activity types. These limitations dull the impact of outreach activities from analogues like MDRS, but school children and teachers have rarely been asked exactly what they would like to see and how they would like it communicated.

II. Survey Methodology for School Groups

Analogue bases can be scientifically valid locations for testing technologies, human and exploration procedures [8] and when bases are placed in locations geologically and appearance-wise analogous to their target destination they are a great opportunity for outreach. For example, spacesuits such as the OeWF Aouda X were evaluated for temperature control in wind tunnels and ovens, but also in analogue bases like the Omani desert – a much more appealing and newsworthy demonstration from an outreach point of view [9][10].

This study was carried out to find which outreach activities and topics pupils are most interested in seeing MDRS crews complete – and how they would like to hear about it. In post-mission school visits, the authors gave a 25-minute talk on space exploration and the use of space analogues to prepare for life on the Moon or Mars; students then completed detailed surveys. Teachers and secondary school students were asked which methods of sharing outreach information they preferred (social media sites, blogs, emails etc) and then all groups were surveyed for their opinions on certain suggested outreach activities and topics. The research also investigated whether pupil preference changed due to factors such as age, gender or British Science Association Audience Group.

The sample was limited by time and resources and none of the authors are qualified or experienced sociologists, so the data merely gives an initial understanding of pupil / teacher preference, requiring substantiation. It nevertheless adds to our knowledge of space/STEM outreach and can be used to improve current strategies. The authors' personal school contacts and the STEM Ambassador Scheme (via Leicestershire Education Business Company, LEBC) were used to secure sample audiences [11]. Altogether circa 400 pupils from 7 schools (see table below) supplied data quantifying their various views and preferences.

TABLE 1. SCHOOL TYPES, CLASSES AND STUDENTS SURVEYED

School Type	Classes Involved	Students	Staff
State Secondary (Leicester)	Y10 Separate Sciences (top set) & visiting, interested Y9s)	15m, 25f	1 Physics Teacher 2 UG Physics Student Teaching Placements
	Y10 Separate Sciences (set 2)	12m, 2f	1 Physics Teacher
Private Secondary (Newcastle)	Y10 Separate Sciences (top set)	15m	1 Head of Physics 1 School Communications Officer
	Y8 Chemistry (unsetted)	17f	1 Chemistry Teacher 1 Head of Science
State Secondary - visiting Y8's to below Primary (Hinckley)	Visiting Y8's (had run a voluntary space outreach workshop for primary pupils)	5m, 5f	1 Year 8 Biology Teacher 1 Year 8 TA
State Primary (Hinckley)	Entire Y5 in an assembly	22m, 32f, 1o	1 Year 5 Teacher
	Entire Y6 in same assembly	27m, 28f, 1o	1 Year 6 Teacher
State Primary (Leicestershire)	Y4 Class	12m, 14f	1 Head of Science & Y4 Teacher
	Y5 Class	~30	Surveys en route
	Y6 Class	~30	Surveys en route
State Primary (Leicester)	Y3 Class	~30 (not included in results)	1 Year 3 Teacher (not included in results)
	Y5 Class (1)	11m, 13f	1 Year 5 Teacher
	Y5 Class (2)	10m, 18f	1 Year 5 Teacher
State Primary (Newcastle)	Y5 Class (1)	26m, 30f, 2o combined	1 Year 5 Teacher
	Y5 Class (2)		1 Year 5 Teacher
Total 6 Schools (plus 1 still pending)	**Secondary: 47m & 49f; Primary: 108m, 135f, 4 other-gendered, plus c. 90 other primary pupils reached but no data used**		**18 members of school staff, plus another 3 reached but no data used**

Fig. 1. Table of schools, students and staff reached through this study

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First, some observations and disclaimers must be made. All year 10 classes were separate science GCSE groups (had elected to do the greatest amount of science subjects for GCSE) so were a self-selecting group more likely to be interested in science than peers. The second (smaller) year 8 group were also self-selecting as "interested in science", having planned and run a small workshop on astronaut suits during their school's STEM week and were invited back for this presentation. One secondary school was a private day-school (including the remaining year 8 class) requiring an entrance exam. In all, the secondary school data was useful for studying pupil/teacher attitudes to STEM, space, and analogue outreach activities, but should not be taken as representative of the general UK school population.

The primary schools were more representative of the UK pupil population - all were state schools and standard classes (most year 5s had Space as part of the National Curriculum that year). However, two schools were on a self-elected emailing list as part of LEBC (see above) and, when contacted about a possible Crew 205-member visit, offered an invite. Perhaps this indicates encouragement for pupils to be interested, or participate in, science beyond the normal curriculum i.e. the school and its pupils are potentially more interested in science than the average. A further primary school had a science programme supported by a STEM activity week (including workshops from visiting Year 8s) involving a space industry employee and ex-pupil - indicating that this school may encourage interest in science above the national average.

All surveys were anonymous - and worded slightly differently for primary students to make the language more accessible. Students scored their level of interest out of 10 in different crew outreach activities and in STEM-related topics where space analogues could act as real-world examples. For teachers and secondary pupils, the focus was in ways they would prefer the crew to communicate their outreach information. There were also questions establishing pupil demographics, personal views on STEM subjects / space exploration as a learning topic and spaces allowing written suggestions to be made.

Collected data was analysed by comparing the means and standard deviations (s.d.) of opinions on questions. If the mean score for an outreach option is high, on average students think well of it. If the s.d. is low, the group generally agree on this opinion. High mean and low s.d. suggests topics desired for classroom use, without disenfranchising students who favour it less. More data would be required to assign statistical weight between these factors, so this paper values them equally.

Finally, pupils identified themselves using an edited version British Science Association's (BSA) Audience Model [12] to see if their level of interest in science affected the kind of activities they preferred to see at space analogues. The BSA asks participants aged 16+ to identify which of four statements they identify with most. The categories being **Professionals**: "I enjoy science and intend to take science-based subject choices in later school and see myself enjoying a career related to it", **Engaged**: "I enjoy science and while I can see myself taking some science subject choices, I can't see myself pursuing a career in it", **Inactive**: "I enjoy learning about certain bits of science at school or through TV shows, books, movies etc, but I can't see myself choosing many science subject choices or a career in it," and **Not Interested**: "Science is definitely not for me."

These questions had to be slightly repurposed for young students to improve comprehension. In this paper, BSA audience groups are often described as being 1-4, with 1 being "professional" (the highest natural interest in science), for statistical convenience and clarity – even though a (necessary) deviation from the standard BSA Audience Model.

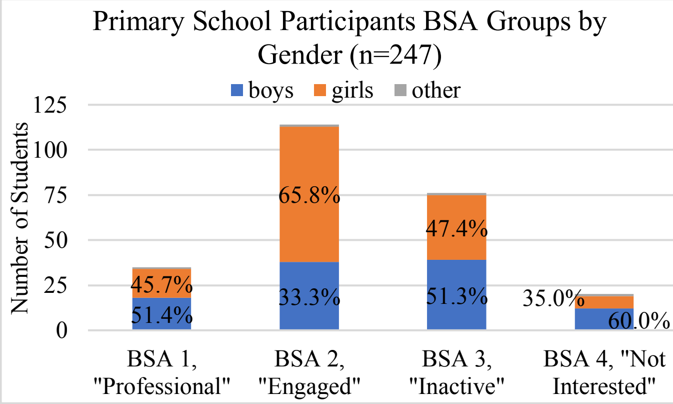

Fig. 2. Demographics of primary school survey participants. A total of 108m, 135f and 4o pupils' results were used.

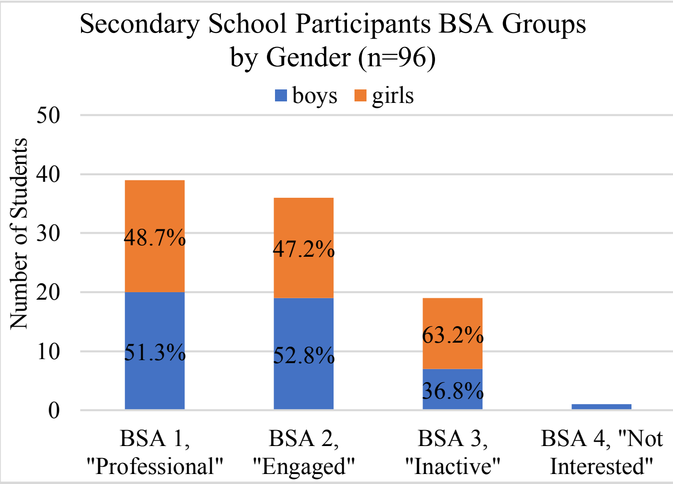

Fig. 3. Demographics of secondary school survey participants. A total of 47m and 49f pupils' results were used.

In this respect it was worth reviewing students' BSA audience group scores to determine if a pattern could be determined before analysing results. This was done to establish if the scheme used was appropriate (or not) as a measure of pupils' self-assessed engagement.

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III. Headline Results

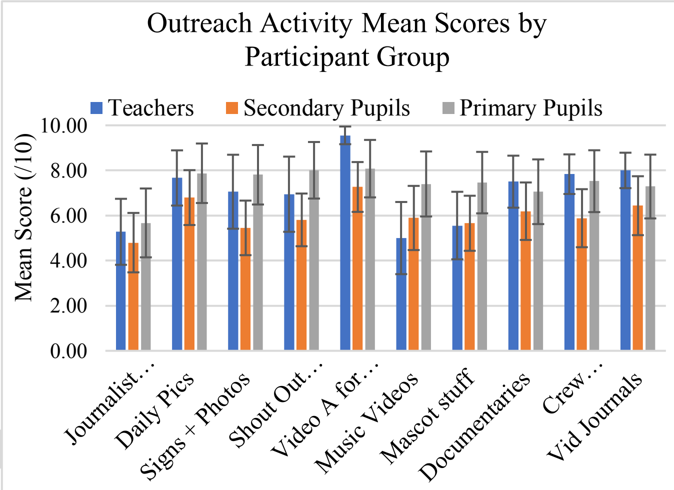
When comparing participants' BSA groups to their "engagement scores" there was a trend for "higher" BSA groups to show higher engagement with STEM. The R-squared regression line statistic for secondary and primary pupils is 30.5% and 29.1%, respectively, showing an expected similarity between the groups, supporting that BSA groups are useful for comparing sampled school groups. The standard deviation of "engagement score" answers of BSA groups' increased as the groups progress from 1-4, across both age groups.

Interestingly, a pupil's BSA group was a stronger indicator of their opinions across multiple results than their gender and this is true for both student age groups. This included their general interest in science and outreach activity preference. Boys of both age groups had lower s.d. variations than girls across all categories of questions (apart from secondary girls' "general interest in science" s.d., which was significantly lower).

Notably, secondary students gave lower mean values, but with lower s.d.'s, than primaries on almost every question. It proved difficult to determine why, but possibilities include increased cynicism among older students about the merit and application of space exploration/analogues to their daily lives, or perhaps that their interest has moved away from simple curiosity about life in space towards difficult technical aspects. It also appeared that younger pupils excited about the talk, may have awarded high scores (all 10/10s) based on immediate emotional reaction, rather than the more measured and analytical scoring demonstrated by secondary school students.

Reviewing participant opinions of **outreach activities:**

- The appetite for "Daily Journalism Pieces" had one of the lowest overall mean scores for both primary and secondary pupils and teachers (although its s.d. was high, indicating a large spread of opinion). This spread was particularly so for primary pupils – perhaps because they had different interpretations of what the reports' content, length or complexity would be like.
- Daily photos scored well across all participant groups, with a low s.d. This is a positive indicator for analogue crews, as daily photo updates are easy to produce and distribute, and are encouraged by the Mars Society.
- Q&A videos also scored very highly. These were notably stated in the survey to not be "video calls", but rather short videos of crew members answering questions emailed in – something that real astronauts regularly do in outreach sessions both in space and on Earth (personal research).
- Primary pupils had a high appetite for "shout-outs" using signs in photos or videos, but secondary pupils disagreed; these answers had some of the lowest means. Both data sets had low s.d. scores – i.e. these opinions seem well agreed. Teachers were split, some rating shout-outs highly, while others voted them the worst - possibly because they weren't clear what a "shout-out" involves or saw it as problematic. Some of Crew 205's "shout-outs" were to individuals or too colloquial, whilst others were to schools, with receiving schools very pleased indeed.
- Secondary pupils rated outreach activities using "mascots" (such as Gus, Crew 205's mascot puppet) lower than primary students, both in absolute score and relative to other ideas.



	Teachers		Secondary School Pupils		Primary School Pupils	
Outreach Activity	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Journalist Reports	5.28	2.93	4.80	2.63	5.67	3.05
Daily Photos	7.67	2.45	6.80	2.43	7.88	2.64
"Shout-out" signs and photos	7.06	3.28	5.45	2.42	7.81	2.64
"Shout-out" videos	6.94	3.33	5.81	2.34	8.01	2.51
Videos answering questions submitted by class	9.56	0.78	7.27	2.21	8.08	2.55
Music Videos	5.00	3.20	5.89	2.85	7.40	2.88
Mascot Photos/ Videos	5.56	2.99	5.66	2.44	7.46	2.73
Documentaries	7.50	2.31	6.19	2.55	7.05	2.87
Crew Interviews	7.83	1.76	5.88	2.57	7.52	2.74
Crew Video Journals	8.00	1.57	6.44	2.61	7.29	2.83

Fig. 5. Mean Results and Standard Deviations for participant groups' opinions of various suggested outreach activities

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BSA group analysis of these activity opinions showed that:

- "Higher" BSA groups generally scored every activity and teaching topic with a higher mean than "lower" groups. However, within each group, activity scores moved relative to each other (i.e. their rank changes); this is an important insight when tailoring outreach strategies and activities to particular audiences.
- In primary schools, the "uninterested" group 4 mostly favoured outreach activities **less** favoured by the other groups - notably music videos, documentaries and crew interviews (only documentaries also rated relatively highly with BSA Group 1).

When results were filtered for **gender**, data indicates that:

- Mean scores for most outreach activities were higher amongst girls than boys (true for both age groups).
- The s.d. values for boys across both school groups tend to be lower than girls, for all outreach activities.
- For outreach activity results, s.d. values grouped by gender were higher than those of their BSA groups (indicating greater agreement) supporting hypotheses that the BSA Audience Model can be applied to children and useful data still extracted.
- Gender groups also had higher s.d. deviations for their "general interest in science" than most BSA groups'.

When **sources** (channels) for outreach are compared:

- Many teachers (especially primary) gave social media sites very low scores, citing the need to instruct pupils that these are forbidden at their age (in accordance with many social media site Terms & Conditions) and forbidden from using them at school – also stressing safeguarding laws preventing students interacting directly with crew members.
- Twitter (despite a significant s.d.) was the highest mean-rated social media preference of teachers - but Instagram was the highest among secondary pupils – also reflecting their preferences for outreach activities using photos and videos, rather than words / articles.
- Both groups also expressed a respectably high mean opinion for using a website (a crew-blog or analogue base website) for updates, with this view also having some of the lowest s.d. values among both groups.

	Teachers		Secondary School Pupils	
Outreach Source	Mean	Standard Deviation	Mean	Standard Deviation
Analogue base own website	7.28	2.72	5.04	2.62
Crew blog	8.00	2.47	4.67	2.79
Facebook	4.22	3.51	3.95	2.71
Twitter	6.22	3.92	4.48	2.92
Instagram	4.39	3.97	6.98	2.95
Updates from your School	6.17	3.07	6.33	2.76
Email Newsletters	7.39	2.17	4.83	2.80

Fig. 6. Mean Results and Standard Deviations for participant group opinions of suggested outreach communication sources

Given these results and comments, teachers should act as online intermediaries for analogue crews, passing updates to students. Safeguarding rules mean that pupils should not contact crew members directly, or vice versa [7]. Websites that **do not** have a feature allowing direct contact (such as a blog without contact details, or official base website) could be shown for students to research in their free time, if approved by the teacher. Sites such as Twitter would be beneficial for analogue crews (requiring less planning and maintenance than a blog) but have messaging capabilities, so should be forbidden without an appropriate go-between. The MDRS website has a section available for crews to instruct "Mission Control" to update with daily photos and journalist reports, which anyone can then visit. But the website is significantly less user-friendly than either Twitter or a dedicated blog.

On outreach **topics**:

- The top interest for both pupil groups was EVA activities, whereas the teachers scored the EVAs second lowest (though with a significantly large s.d.). While EVAs are exciting to students, teachers may see them as inapplicable to the current curriculum, or may not have the knowledge or time to plan and deliver lessons based around them.
- Teachers scored renewable energy and recycling very highly as examples of how analogue bases can benefit real world research (with both means over 8 and the lowest s.d. scores, too). This is helpful from a space perspective; long-term space infrastructure and closed loop systems are increasing priorities as exploration mission plans shift to more sustainable and long-term technology) – and creates an important link to issues critical to curriculum education and future society.
- Like teachers, both students groups rated renewable energy highly as a topic for analogue base outreach – but, interestingly, recycling was in the lower half of ranked topics across both groups.

	Teachers		Secondary Pupils		Primary Pupils	
Outreach Topic	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Recycling	8.94	1.34	6.35	2.19	7.69	2.66
Psychology	4.65	2.57	6.44	2.59	7.84	2.70
Plants & Photosynthesis	6.47	2.72	5.86	2.06	7.44	2.65
Renewable Energy	8.06	2.41	6.64	2.24	8.03	2.53
EVA/Spacewalks	5.47	3.54	7.08	2.53	8.61	2.26
Orienteering/Map s	6.41	3.10	5.89	2.50	8.34	2.34

Fig. 7. Mean Results and Standard Deviations for participant groups' opinions of various suggested outreach activity topics, based on applicable topics linked to space analogue research.

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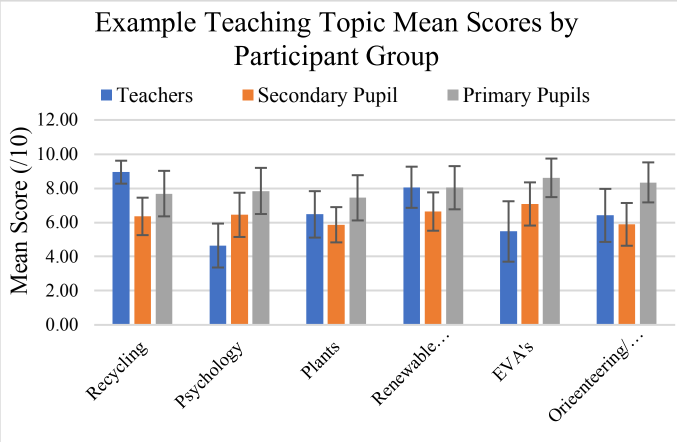

Fig. 8. Graphical presentation of the data in Fig. 7. (above)

IV. Discussion Of Results

When considering the data obtained, ambiguity is a general issue i.e. "documentaries" could be short (a few minutes on a focused topic) or longer (tens of minutes on daily life in the base). "Crew interviews" could be informal and entertaining, or formal, based on promoting scientific purposes. Similarly, with EVA, there could be big differences between what pupils expect and what the crew can deliver, so improvements should be made to the survey by reviewing the pre-survey presentation to filter out instances where students might be misled or confused.

Some results support the compatibility of the BSA Audience Model within this study, e.g. group 1 secondary pupils support using analogue base websites (3rd highest mean score) but the mean for this progressively decreased across other groups, suggesting the most scientifically interested students were most committed to searching for analogue information in free time.

Teachers are acutely aware of the need to balance outreach with safeguarding laws and preferred methods where students had no direct contact with analogue crews or vice versa (i.e. outreach activities requiring teachers as an intermediate point of contact). Schools would therefore need **prior** knowledge of the mission to increase the effectiveness of outreach. Building an engaging outreach relationship between crew members and schools could be achieved in a number of ways - there were suggestions for pre-mission school visits; students providing items for use at analogue bases; students designing or choosing parts of an experiment to be performed; or a competition to design a crew's mission patch.

The question of how to identify interested schools should also be discussed; some follow science communications social media channels and others will be open to direct contact – but it may prove preferable for analogues to use intermediaries like STEM education charities (just as this study used LEBC), thus protecting both analogues and schools from safeguarding issues. Analogue crews would benefit from having a blog, website or social media page with published pre-mission details, to establish mission credibility and explain how schools and other institutions could get involved.

A repeated suggestion from teachers and students alike was to film and explain an experiment being performed at the base. One secondary physics teacher even suggested letting students design experiments for the crew to perform on site. This could involve on-site comparative experiments that could be tested against student-conducted "control" experiments performed in the classroom, as well as novel experiments explicitly unique to the analogue environment. Both techniques would demonstrate the analogue's scientific viability as a wider educational opportunity.

Another outreach activity with high mean scores and low s.d. values across both school groups and teachers, were Q&A videos. Crews should avoid audiences believing this to be a live exchange, as most analogues (including MDRS) prohibit this. Despite this being stated clearly on the survey, some respondents' notes suggested they mistakenly interpreted it as live video calls. If the suggested technique were utilised, it would be imperative that crews establish contact with interested audience groups prior to mission execution to establish appropriate lines of questioning and deliverable deadlines.

V. Conclusions

The results indicate a range of opinions and preferences for outreach activities at space analogues like MDRS; some match across distinction lines and between groups with s.d. data that proves them to be agreed on.

Twitter or blog-based websites were the highest ranked outreach medium between crew and schools, but safeguarding rules must be observed. Suggested techniques include the use of teachers as intermediaries with no direct crew-student contact outside of faculty supervision, and the use of STEM Outreach intermediaries as recruitment partners for crews. There are varying opinions on current MDRS outreach activities (Daily Photos and Journalist Reports), although image-related material such as photos and videos, are usually preferred to written reports.

The high interest of pupils and teachers in Renewable Energy technology is advantageous as this is an important research topic for analogue bases – many of which are studying systems which recirculate ECLSS resources as much as possible for improved long-term sustainability [8]. Related subjects such as recycling, despite slightly more mixed results, can also feature if desired – explaining how technology being used or tested at space analogues can be useful for terrestrial life, too.

Given strong student interest, analogue crews and teachers should consider the best approaches of making EVA material relevant to the curriculum. This will require careful planning to optimise fidelity of crew produced products and acutely target material to the desired audience groups (e.g. at MDRS, good

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voice recordings of crew may not be achievable due to helmets being in the way and EVA time and data restrictions can lower the quality/number of images and videos the crew are able to process and upload).

There is a strong interest amongst pupils and teachers for space outreach – so managers of analogue stations should encourage and guide crews accordingly. Pro-active planning and materials give analogues bases a great opportunity to maximise outreach results. Particularly to school and teacher audiences, through certain social media or website channels and using preferred outreach products whilst safeguarding systems are used. While these suggestions are not presently accurate enough to be reliably applied to entire school populations, the authors hope the data lends some insight to aspiring crews' outreach programmes.

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Commercial access for UK/ESA student experiments on board the ISS

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Abstract—**School students in the US have the ability to commercially fly experiments on-board the International Space Station (ISS) via programmes like the Nanoracks sponsored Student Spaceflight Experiment Program (SSEP). Programs like SSEP do allow international schools to participate but similar programmes do not currently exist within the European Space Agency (ESA). ESA does, however, support commercial access to space via companies like Airbus and Kayser Italia. A key principle of SSEP is that students propose to fly experiments that will work within existing spaceflight hardware. This is similar to the idea of using standardized CubeSat platforms in education and ESA's long-standing use of standardized Experiment Containers (ECs). These ECs form the starting point for Airbus and Kayser Italia's commercial access programmes. In 2018 we were selected by the UK Space Agency to develop and fly a UK national payload to the ISS. This payload will conduct scientific experiments proposed by ourselves, international partners, and schools in the UK. All experiments will take place inside ECs that are refurbished, and flight qualified in the UK. If we can successfully conduct student experiments during this mission, we will have demonstrated the possibility of conducting UK student experiments in space via a UK company. This should pave the way for UK-based commercial access to the ISS that could be used by schools much like the US based SSEP.**

Keywords—Student spaceflight; experimental cassette; commercial spaceflight; CubeSat; schools

I. Introduction to Student Spaceflight Experiments

Since June 2010, students in the US have had commercial access to space and the International Space Station (ISS) through programmes such as the Nanoracks-sponsored Student Spaceflight Experiment Program (SSEP). Platforms such as Nanoracks can provide regular access to space on the condition that the financial costs can be met. The SSEP is a model US National Science, Technology, Engineering, and Mathematics (STEM) initiative for 5-16 year old students, which is intended to inspire the next generation of America's Scientists and Engineers (1). It is the product of a joint partnership between the National Center for Earth and Space Science Education (NCESSE) and Nanoracks, LLC. Each round typically engages three hundred or more students, and they compete in local Flight Experiment Design competitions. The competition runs in a manner highly similar to that of grant proposals for scientists and thus, is an accurate depiction of future research as a space life scientist in the planning, feasibility and safety testing, and actual flight of an experiment.

II. US-Based Student Spaceflight Experiment Provision: How It Works

In the US, individual school districts apply to host an SSEP, at a cost of $25,000 (1). The basic model for these programmes is to pay money for access, design, and to fly a spaceflight experiment. Each district can secure a 'mini-lab' thereby obtaining the platform to fly the experiment in space, led by the experiment design competition. The SSEP provides all teaching and student resources and other resources for the engagement of the community including conference attendance or museum visits [1]. All experiments proposed, similar to research-led experiments, must pass a safety review to ensure that the experiment and samples pose no risk to the crew, resupply vehicles, or the ISS. Indeed, the level of risk permitted depends upon the toxicity of samples and how well they are contained, and this highlights the benefits of Nanoracks in the US and Experimental Cassettes (ECs) in Europe as a standardised platform, which provides protection of experiments for use in spaceflight research.

III. A Brief History of Life Sciences Flight Facilities Developed for the ISS

Facilities originally designed for use on the ISS were to host experiments in evolutionary biology, developmental biology, gravitational ecology, cellular and molecular biology, and organismal and comparative biology [2]. Opportunities have expanded on the ISS to accommodate research in cell culture, an insect habitat and an animal habitat for rodents, an aquatic

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facility (small fish and aquatic specimens), a specialised egg incubator (developmental biology), and even a platform for research with small plants (European Modular Cultivation System (EMCS)) [3]. Habitats provide food and water, light, air, waste management, and provide control of both temperature and humidity for a multitude of organisms [3]. Broadly, these habitats have been established to investigate the effects of spaceflight on physiology. Spaceflight is associated with many physiological stressors including microgravity, radiation, changes in tensions of oxygen, carbon dioxide, and nitrogen. In order to determine the independent effects of microgravity on biological experiments in space, it has been necessary to develop centrifuges for application on the space station. The presence of a centrifuge and comparison to ground reference controls, allows elucidation of the effects of launch/landing accelerations, vibration, microgravity, and radiation [4]. Student-led experiments using an in-flight centrifuge such as Kubik are now a commercial reality in Europe through the use of ECs developed by Kayser Italia.

IV. The Development of Student Led Experiments That Fit Within This Setup

Physical space onboard the ISS is finite, therefore life science experiments and particularly those proposed by SSEP must be space efficient. Experiments designed by students using the Nanoracks platform, for example, can use one of three fluid mixing enclosures, specifically designed as hardware for spaceflight research [5]. There is typically a short turnaround between selection of proposals and flight (c. six months) limiting opportunities for validation of equipment and science verification testing [5]. European-led biological and life science experiments in space take place in incubators including Kubik, Biobox, EMCS, and BioLab [4].

These European incubators can house ECs (Fig 1) in a single temperature-controlled environment where some samples are at 0g and others can be maintained at 1g through an integrated centrifuge [6]. These incubators permit full automation of experiments during ISS flights, making it time efficient and little imposition for crew. ECs have been designed that slot into spaces within either Biobox or Kubik and they can be supplied with power to manipulate experimental conditions. Indeed, Kayser Italia has developed thirteen experimental units for use in space, which allow the culture of bacteria, cells, tissue culture, model organisms including *C. elegans*, and plants [6].

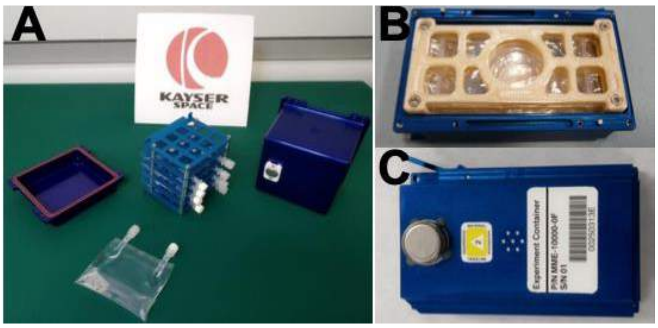

Fig 1. ECs suitable for use in student spaceflight experiments. (A) EC developed for the ESA Rotifer Investigation and (B) open and (C) closed image of the MME EC. Photo credit Kayser Space.

V. Benefits of Student Spaceflight Experiments for Engagement in STEM

Student spaceflight experiment programmes are valuable for education outreach activities through inspiring the uptake of Science, Technology, Engineering, and Mathematics (STEM). Furthermore, they also help stimulate the next generation to take careers in STEM subjects and are the future of the space industry, including spaceflight research. Whilst programmes such as the SSEP do allow international students to participate, they are not widely advertised within European countries, and thus, uptake in these programmes from European countries is poor. Both the UK and Europe have our own respective Space Agencies, so it is no less important to inspire our future Scientists than in the USA.

VI. A European Platform for Student Spaceflight Experiments

ESA currently offers the Fly your thesis! programme, which offers European students the opportunity to design, build, and fly an experiment as part of a Masters or PhD thesis [7]. These experiments are then implemented on either a parabolic flight, a drop tower, a centrifuge, or a CubeSat [7]. ESA does support commercial spaceflight opportunities through companies like Airbus and Kayser Italia, however, the development of spaceflight hardware is a significant cost and prohibitively so for student projects. Thus, all experiments proposed in the USA programmes must work within existing flight hardware. In Europe, companies such as Kayser Italia (http://www.bioreactorexpress.space) and Airbus (http://www.kiwi-microgravity.com) have used standardised ECs for some time [8,9]. This EC platform has made access to space a commercial reality within Europe, similar to Nanoracks in the US. The EC is an aluminium box of approximately 20 x 40 x 80 mm (Fig 1). Just about any experiment that can fit within this box can be flown. As mentioned above, existing hardware allows the ECs to be flown with or without power, in or not in a temperature-controlled incubator and using a variety of previously developed hardware inserts. We have recently used this platform for the Molecular Muscle Experiment [10] and have recently been granted one of the first UK national payloads to fly to the ISS. In our current flight project, Molecular Muscle Experiment-2, we have been granted permission to fly three student led experiments within these ECs. If we can successfully conduct student experiments during this mission, we will have demonstrated the feasibility of conducting UK student led experiments in space via a UK company, thereby providing proof in principle that schools can commercially fly experiments within the UK/ESA.

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On the effectiveness of an interleaved curriculum in increasing exposure of secondary school pupils to astronomy and astrophysics

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Abstract— Despite the publics continued fascination with astronomy and space, the numbers of students who spend at least 50% of their higher education time studying astronomy based topics has fallen since 2010, and the overall number of first-year students studying over 50% astronomy topics is under 1000. Astronomy is a unique vehicle in engaging students in science, covering the very small and the very large scale questions in equal measure. The lack of astronomy within the current physics curriculum, and the relatively low number of centres offering GCSE Astronomy as an option means that many students will only study one topic of astronomy through their entire secondary education. Interleaving is a method of teaching whereby core topics are taught several times through the thread of separate contexts. This paper proposes the introduction of astronomy into the physics GCSE curriculum as a vehicle to deliver varying topics from radiation to waves. This would increase students' exposure to astronomy through their secondary education, and allow more students to experience astronomy in much more depth.

I. Introduction

Astronomy and astrophysics have always been subjects that capture the imagination of the general public. From the earliest cave paintings of the Pleiades open cluster over 16'000 years ago, to 15% of the global population tuning in to watch the 1969 Apollo 11 landings, human beings have been predisposed to wanting to learn about what lies beyond our atmosphere. Despite this wide reaching fascination with the subject, the headcount of students spending at least 50% of their education time on Astronomy related topics has fallen since 2010 [1], despite headcounts on physics courses increasing over the same period, and the total numbers of undergraduate first year students studying at least 50% astronomy is well below 1000 [1].

Currently, Astronomy is available to students between 13-18 years of age in 3 possible ways. There are 2 optional methods of gaining knowledge of astronomy in the A-Level Physics optional module, and the Edexcel GCSE Astronomy course. The optional A-Level module is, however, only taught in the final term of year 13, when students have already made university choices, and they must have already decided they wish to study physics at A-Level. The Edexcel GCSE Astronomy allows students to study the subject earlier in life, however, it is currently offered by very few centres. Only 1293 students entered into the 2019 GCSE Astronomy exam, out of over 500'000 students who took GCSEs in June 2019 [2]. Despite the fact that all students taking GCSE science will experience some astronomy in their physics classes, this is usually in the form of one single topic, and includes a very narrow section of content with very specific learning outcomes which are solely relevant to learning a small number of basic facts about astronomy, such as the Solar System, and the life of a star.

Whilst astronomy continues to show itself as a hugely dynamic, inspiring, and broad topic within science, its uses in education tend to be very narrow and only taught over a short period of time. As a consequence of this, students will receive only a very basic education in a very small section of astronomy and space during their life in secondary and further education, unless they already show great interest in the subject and find a school or external centre offering either the GCSE or A-Level options in Astronomy.

II. Theory

Interleaving has been a recent research phenomenon in education that has increasingly shown promise. Studies in 2008 showing improvement in mathematical skills over a 3 month period [3] and another study showing improvements in subject knowledge in 2008 [4] have been widely cited as evidence in favour of this method. It involves the weaving of skills and concepts throughout themes across a longer time period, with repetition in different contexts and has shown promise in overcoming one of teaching's biggest problems, long term recall. The use of interleaving in a curriculum not

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only allows for contextual teaching, with more real-world application of knowledge to draw on and context to 'hang' knowledge from, but also to ensure skills and concepts are practiced on multiple occasions and in different ways, building a deeper knowledge of the topics at hand.

This method of teaching is already prevalent in other subjects at Key Stage 4 and in further education. For example, English departments across the world teach skills such as analysing texts and identifying literary devices through the threads of books and novels. These create a storyline for students to follow and gives a more realistic context than simply teaching the pure concept. The use of a storyline to ensure concepts are consigned to long-term memory rather than forgotten quickly is long established in educational research[5]. It allows the mind to use this story and create a connection with the meaning of the concept[5].

III. Methodology

The current physics curriculum in year 9 taught by the author includes topics such as waves, heat transfer, energy stores and astronomy. It was proposed that, in order to invigorate and rejuvenate the year 9 physics course, the year could be split into two 'themed' terms. The first of these terms would be titled 'Astronomy'. This term will offer a significant portion of the topics covered in the previous year 9 curriculum, but threaded through the context of astronomy.

The topics of waves, radiation, heat transfer, motion and gravity will all be taught through a broader astronomical context. This aims to enable the students to receive the same level of knowledge in GCSE specification topics, while giving them a far more in-depth experience of astronomical concepts such as black holes, stellar structure and human spaceflight that are not discussed in the standard GCSE physics curriculum [6].

A good example of this is the teaching of the electromagnetic spectrum and waves through the context of astronomical observations, including explanations of the uses of different wavelengths in astronomy and how these can give us different information about objects we observe. This gives students a more in-depth understanding of astronomical techniques, scientific method and more importantly, makes it easier for students to see what the concepts mean in a real-life, scientific scenario. This is echoed in another example used in the new curriculum, with a greater description of how gravity gives rise to structure in the universe, from very small to very large scales, showing students the inspiring concept of the immense scale of the universe, whilst enabling them to see an important application of the effects of gravity on our universe.

This use of a themed term also lends itself to including an increase in project-based learning. For example, students will spend a week at the end of the Autumn term across all 3 sciences working on a presentation of their design for a base on another planet or moon, including aspects of the topics that were threaded through the term. This project-based group work has also been shown to improve engagement for female students, who have been found by studies to generally prefer group work and work which rewards effort rather than simply the quality of answers [7]. This is an important step in improving the well-documented gender imbalance within physics, and this curriculum aspires to enhance sense of creativity involved with the interleaved curriculum, providing greater engagement for female students than the traditional formulaic topic-fact-equation style of teaching in physics.

The effects of this new curriculum will be tested by three methods. Firstly, there will be observations conducted throughout both the physics department and the science department in general with a specific focus on both quantity and quality of student engagement. In addition, the end of term test results for each given themed term will be compared with previous years' topic tests, and the end of year test will be compared with previous years' averages, in order to see if the students have improved their subject knowledge of the necessary content. Finally, in the long term, there will be data taken on the number of students studying A-Level Physics and physics in higher education, and how the numbers compare between students who have taken the new and old curricula respectively.

The new curriculum aspires to improve engagement within the classroom, and as a consequence improve students' subject knowledge and test results. In the long term it is hoped that this will translate into an increased uptake of students in both A-Level Physics, and even physics and astronomy-based courses in their higher education pursuits.

IV. Conclusion

The physics curriculum in Key Stage 4 has been updated so as to thread the traditional GCSE topics through the context of in-depth astronomical concepts. It is predicted that this could improve students' engagement with the inspiring nature of astronomy and space science, alongside improving students' knowledge by threading the traditional topics through varying contexts and applying the knowledge in different scientific situations.

This will be initially brought in with an autumn term theme entitled 'Astronomy', including the topics of 'Stellar structure', 'Origins of the Universe' and 'Human Spaceflight'.

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Flight Software Development for the EIRSAT-1 Mission

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Abstract—**The Educational Irish Research Satellite, known as EIRSAT-1, is a student-led project to design, build, test and launch Ireland's first satellite. The on-board software for this mission is being developed using Bright Ascension's GenerationOne Flight Software Development Kit. This paper provides an overview of this kit and of EIRSAT-1's on-board software design. Drawing on the team's contrasting experience with writing entirely custom firmware for the mission's science payloads, this work discusses the impact of using a kit on the software development process. The challenges associated with the educational nature of this project are the focus of this discussion. The objective of this paper is to provide useful information for other CubeSat teams assessing software development options.**

Keywords—CubeSat; software

I. Introduction

EIRSAT-1 is a 2U CubeSat being developed at University College Dublin (UCD) as part of the Fly Your Satellite! programme run by the Education Office of the European Space Agency (ESA). The EIRSAT-1 project is an interdisciplinary, student-led effort to launch Ireland's very first satellite. The mission's primary objectives are educational, with the aim to develop the capabilities of the Irish higher education sector in space science and engineering and inspire the next generation of students towards the study of STEM subjects. To facilitate these aims, EIRSAT-1 will fly three novel experiments that have been developed at UCD [1]: the Gamma-ray Module or 'GMOD', a bespoke gamma-ray detector [2]; the ENBIO[1] Module or 'EMOD', a thermal materials experiment; and Wave-Based Control or 'WBC', a software-based attitude control experiment [3]. Custom hardware has been developed by the EIRSAT-1 team for both the GMOD and EMOD payloads. Excluding the Antenna Deployment Module, which has also been developed at UCD [4], the remainder of the CubeSat platform consists of Commercial Off The Shelf (COTS) components supplied by Clyde Space Ltd[2] [5].

EIRSAT-1's main flight software will run on a Clyde Space On-Board Computer (OBC), with the FreeRTOS real-time operating system. This OBC is a standard CubeSat kit PC-104 subsystem, that is built around a MicroSemi SmartFusion2 System on Chip (SoC), and includes an ARM Cortex M3 processor. The mission's main software, which is being written in the programming language C, is being developed using v18.3 of the Bright Ascension GenerationOne Flight Software Development Kit[3] (FSDK). In addition to the OBC-run software, custom software is also being developed for the payload microcontrollers, which are Texas Instruments MSP430 microcontrollers. The EIRSAT-1 software will undergo its first full mission test during an ambient test campaign set to begin in late 2019.

This paper provides an overview of the Bright Ascension GenerationOne FSDK and of EIRSAT-1's flight software, with a focus on how the design and development of the latter has been shaped by the FSDK. Using the team's experience with developing custom firmware for GMOD and EMOD without the use of a kit, the impact of using the FSDK on the software development process is discussed, particularly with regards to the challenges associated with a student project. Alternative software development options to the FSDK are also given and the software options followed by other CubeSat teams are considered. This work offers an insight into the EIRSAT-1 team's experience with kit-driven development, helping others to determine if an FSDK-like software solution is suited to them and their mission.

II. Flight Software Development Approaches

The Bright Ascension GenerationOne FSDK was chosen by the EIRSAT-1 team to address the challenges associated with student-led development. In particular, the challenge and risks associated with maintaining the project's schedule (discussed further in Section V). Furthermore, as the FSDK is provided with software to interface Clyde Space COTS components, which are used on EIRSAT-1 [5], the team considered that this kit was very well suited to the project. However, due to differing mission, hardware and/or software requirements, this may not be

1. http://www.enbio.eu/
2. https://www.aac-clyde.space/
3. https://www.brightascension.com/products/flight-software/

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the case for every project. Therefore, this section mentions alternative flight software development options that are available to and used by CubeSat teams.

A. KubOS

KubOS[4] is an open-source software development kit and framework that builds on a customized Linux distribution. ISIS, Pumpkin and Beaglebone OBCs, as well as a selection of additional COTS devices, are all supported. Options are also provided for the programming language used for development, including for C, Python and Rust.

B. Core Flight System (Starter Kit)

The core Flight System (cFS) is an open-source flight software platform created by NASA's Goddard Space Flight Centre. cFS has flight heritage originating from multiple larger NASA missions, including the Lunar Reconnaissance Orbiter mission. However, more recently, the platform has been adapted to suit a wider variety of mission. The cFS Starter kit, also known as OpenSatKit[5], is a development kit that facilitates reuse of cFS software for other (including CubeSat) missions.

C. CubedOS

The services provided by CubedOS[6] are very similar to those provided by NASA's cFS, however this framework has been written using the SPARK/Ada programming language, and associated tools, as opposed to C. The SPARK toolset and code aim to facilitate development of a more reliable software image by removing complexity associated with other programming languages to reduce the risk of development errors.

A detailed comparison of the frameworks provided with A-C is given by [6].

D. Open-Source CubeSat Software

The Libre Space Foundation, in collaboration with the University of Patras, developed and constructed both software and hardware for UPSat[7], a 2U CubeSat launched in 2017. As a primarily objective of the Libre Space Foundation is to provide open-source access to space technologies, a Git repository containing UPSat's flight software is freely accessible for CubeSat teams to use.

E. Custom

To satisfy mission requirements, many CubeSat teams decide to develop custom flight software from the ground up (e.g. [7], [8] and [9]), without the use of software solutions like the Bright Ascension FSDK or those mentioned in this section. While discussing the impact of using Bright Ascension's FSDK on the development of EIRSAT-1's flight software in the following sections, the decision of these teams to develop software from the ground up is also considered.

III. GenerationOne Flight Software Development Kit

The Bright Ascension FSDK facilitates rapid development of flight software for small/nano-satellite missions. This is primarily achieved using a model-based software development approach, known as Component-Based Development (CBD).

In CBD, a "component" is defined as a reusable, standalone software module that plays a specific role (e.g. logging data) and provides a set of functions and parameters related to that role. A software image with a range of functionality is then created by linking multiple of these components together in a software "deployment". Within a given project, components share a standard interface, commonly referred to as a "container", through which components interact, and which also allows for easy interchange of the components that make up a deployment. The primary aim of this approach is to separate complex software systems into simple, independent components that can be easily and individually designed, tested and maintained.

CBD relies on demands reoccurring across a type (or range) of software product(s), where reusability of components which satisfy these demands is the key concept driving the success of this approach. In the case of the FSDK, Bright Ascension have built their product around general software functions that are required for any space mission (e.g. hardware interfacing, data handling and communication protocols). Therefore, the FSDK is provided with a software framework, which provides some supplier-specific (including Clyde Space), low-level hardware interfacing and OS (including FreeRTOS) abstraction; as well as libraries of pre-validated software components, many of which have flight heritage. In addition to these components, useful development tooling (plugins for the Eclipse development platform) is also provided with the FSDK.

CubeSat missions launched with flight software that has been developed using the FSDK[8] include UKube-1, Centauri-1 and Centauri-2, Audacy Zero, SeaHawk-1 and IOD-1 GEMS.

IV. EIRSAT-1 Software Design

A. Main Flight Software

Grouping the main software components that are required for the EIRSAT-1 mission, the components can be divided into three distinct tiers, as shown in Fig. 1, which are:

- the Management Tier– manages when the system's functions are called;
- the Capabilities Tier– provides access to the system's functions; and
- the Hardware Tier– provides low-level interfaces to the system hardware.

These three tiers represent the different layers of abstraction in the software, where the components in the lower tiers provide abstraction for components in the upper tiers. This architecture has been very much shaped by the FSDK, where the libraries of kit-provided components have been specifically designed to allow for hardware, OS and protocol independence [10]. Use of the team's resources is also well captured in this architecture, as

4. https://www.kubos.com/kubos/
5. https://opensatkit.github.io/menu/about.html
6. http://cubesatlab.org/CubedOS.jsp
7. https://upsat.gr/
8. Information on current missions launched with software developed using the FSDK is available at https://www.brightascension.com/news-events/

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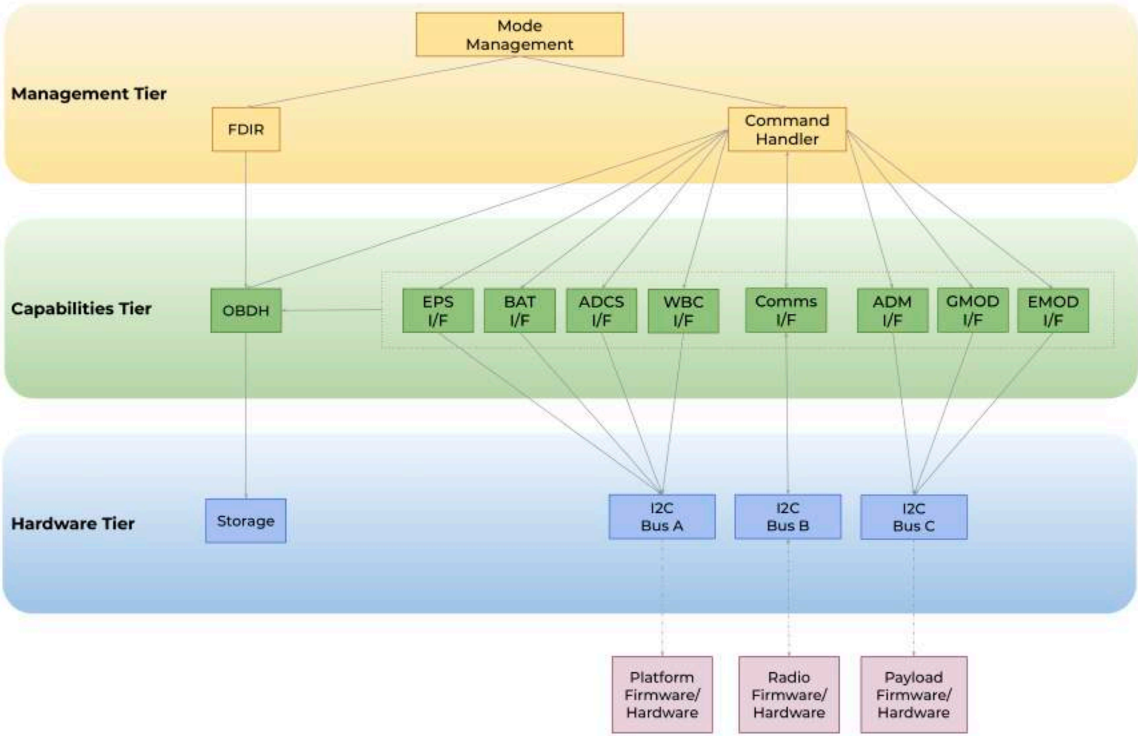

Fig. 1. Overview of the EIRSAT-1 software architecture, where *I/F* refers to the software providing an interface to the Electrical Power Supply (*EPS*), Battery (*BAT*), Attitude Determination and Control System (A*DCS*), Transciever (*Comms*), Antenna Deployment Module (*ADM*) and science experiements, *GMOD, EMOD and WBC* (uses the ADCS hardware). *FDIR* refers to the Fault Dectection, Isolation and Recovery components and *OBDH* refers to all On-Board Data Handling software.

the development time required for different aspects of the flight software increases for components in upper tiers, compared to that of the lower tiers (i.e. as mission-specific software becomes increasingly required over standard kit-provided software).

B. *Platform and Payload Software*

Flight-ready firmware is provided by Clyde Space for the COTS platform hardware.

For the GMOD and EMOD payloads, firmware is being developed in-house without the use of development kits/tools. This firmware will provide an interface to the hardware components of the GMOD and EMOD experiments, and will communicate with the OBC via I2C. As the payload motherboards are slave devices to the OBC, the requirements on each firmware are relatively simple and are based around the need to collect and temporarily hold data in flash memory, while waiting for instruction from the OBC. As a result, the team did not adopt CBD for this development. Instead, given the limited and well-understood requirements on the systems, the payloads' firmware are being developed as a whole system in a more traditional sequential process.

Components in the main flight software then interface with this firmware to provide access to platform and payload data and functions (i.e. the interface components in Fig.1).

The architecture resulting from this development process is similar to that described for the main flight software, where software interfacing hardware is used by the software that provides functionality. However, as the payload firmware is not developed within components, little distinction between or abstraction across the tiers exists in this scenario. Furthermore, as a result of not using any development kit or tooling (i.e. developing the code from scratch), the resources of the team have been much more dedicated to lower-level aspects of the firmware as opposed to the software in the upper tiers, completely in contrast to the development time given to the different tiers of the main flight software.

V. Impact of Using a Kit on the Development process

The EIRSAT-1 team have had the opportunity to develop parts of the mission's software both with and without the aid of a development kit. Although, the latter was done for the comparatively smaller software part (i.e. the payload firmware), the different experiences had by the students working on each part allowed the team to identify how the use of a kit has impacted the flight software development process. These considerations are discussed in this section for a mission team to review when determining whether or not a development kit is suited to their project. This content specifically draws on the EIRSAT-1 team's experience with the Bright Ascension FSDK, however, many of the considerations are applicable to any development kit and have been discussed in a general context, as well as from the perspective of a student-led team.

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A. Schedule

The FSDK was initially chosen by the EIRSAT-1 team to allow for rapid software development. As mentioned in Section III, this is primarily facilitated by providing libraries of ready-made software components as well as development tooling. However, development kits like the FSDK, are also provided with additional aids to help achieve not only fast-paced development, but also rapid learning, implementation and testing. In particular to the FSDK, this includes: well-developed learning materials, such as a detailed user manual, tutorials and example code; tools for deploying, testing and documenting software, including a unit testing framework, a mock ground segment application and methods of generating documentation directly from source code; and a long-term customer support service.

Drawing on the experiences of EIRSAT-1 team members (both new and existing), the learning and development time/effort required for the payload firmware compared to the main flight software is substantially higher. This demonstrates the effectiveness of the FSDK and its usefulness with regards to maintaining a project schedule. This is a particularly important consideration for a student-led project, where turnover of team members can be high, as (new) students complete (begin) their degrees, modules or projects through which they are involved.

B. Flexibility

To fully benefit from using a CBD kit with pre-existing, pre-validated components, a software project should be shaped by and built around the services that are provided with a kit (e.g. the FSDK is provided with collections of data handling, fault detection, automation and task management components [10]).

While this aspect of using a kit is very well suited to the EIRSAT-1 project (mainly due to significant flexibility of software design given the team's inexperience with flight software development) projects that are less flexible with regards to the implementation of functionality in software may not be so suited to development with a kit. In this case, development from the ground up, or using an alternative software solution (see Section II), may instead be needed to meet a mission's requirements. For example, the Galassia CubeSat, built by a student-led team at the National University of Singapore, identified that the objectives of the mission, including the objective to develop a reusable software framework for future missions, required software development from scratch [7].

C. Risk

The failure rate of CubeSat projects is high, with 40-50% of university-class CubeSat missions failing to achieve their primary mission objectives [11]. Furthermore, at least 2% of CubeSats are thought to fail due to software-related issues.

The FSDK is provided with libraries of robustly tested software components, many of which have flight heritage. Furthermore, this kit contains platform (for e.g. Clyde Space and Nanomind) and OS (for e.g. FreeRTOS and Linux) specific software. The EIRSAT-1 team have found these components to be highly dependable. Therefore, a high-standard kit such as the FSDK, which has been created by a team of developers with space software expertise and has in-orbit validation, can be invaluable for a project to mitigate the risk of mission failure, which is particularly prevalent for student-led projects.

D. Cost of Resources

Two costs should be considered: "Cost A", which is the cost of purchasing the product; and "Cost B", which is the cost of resources. Unlike Cost A, which is completely subject to whether a development kit is purchased or not, Cost B is inevitable for any software project. Cost B is the overhead cost associated with getting the software product (in this case the flight software) to a finished state. Managing Cost B, which is influenced by the resources (i.e. manpower, expertise and skills) available to a project, is essential to the success of any project. Therefore, to determine if a development kit is suited to a project, the team must first make a realistic assessment of their available resources, and then estimate the added overhead cost that would be required to develop software that fills the role of the kit-provided software, "Cost B(A)".

If a shortage of resources is identified (i.e. Cost B(A) >> Cost A) in the early stages of a project, as it was for EIRSAT-1 project (due to a lack of expertise but also due to the fact that the team is composed of masters and PhD students, many of whom have projects that are not related to the mission), and the project budget allows for it, investing in Cost A, to effectively outsource a substantial fraction of the groundwork development, is hugely advisable.

E. Cost of Reusablilty

A consequence of using a proprietary development kit is that no in-house intellectual property is developed with regards to a reusable software framework. In addition, the knowledge base of the team with regards mission software design is only developed within the confines of using a kit. Therefore, teams that have chosen to use a kit for their current software project, as is the case for the EIRSAT-1 team, must either: 1) re-invest in another license for the same kit or 2) overcome the costs associated with Cost B(A) for future missions. This is a major consideration for a mission team where the short-term benefits of and need for a development kit must be deliberated with the long-term plan.

In the case of EIRSAT-1, the benefits of rapid learning and development, as well as having the support of the Bright Ascension support team were considered as a necessity to the EIRSAT-1 project, particularly as this is a first-time project which must keep up with the schedule of the Fly Your Satellite! Programme. As a result, for EIRSAT-1, the need for a development kit outweighs the current need for freer future reusability of software. However, for teams with more resources (e.g. experience of developing a mission), that have a long-term plan involving multiple missions (e.g. CubeCat[9] and PolySat[10]), in-house software development becomes a more profitable consideration.

9. https://nanosatlab.upc.edu/en/missions-and-projects
10. http://www.polysat.org/launched and http://www.polysat.org/in-development

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VI. Discussion and Conclusions

The decision to use a development kit for a software project is hugely influenced by both the project objectives and the scenario in which the CubeSat project is being developed (e.g. development in an industry vs. academic environment). Therefore, Section V discusses the impact of using a development kit, specifically Bright Ascension's GenerationOne FSDK, on the development of EIRSAT-1's main flight software with sufficient background information on the EIRSAT-1 mission, team and software project to allow other teams to review this work and make an informed judgment on the FSDK in light of their own scenario. Although the EIRSAT-1 team do not have a comparable experience of developing a mission's main flight software without the aid of a development kit, development of payload firmware without the use of a kit or tooling was used to consider the impact of using the FSDK on the project.

This work shows that kit-driven development has been extremely beneficial to the EIRSAT-1 project, helping the team to overcome challenges faced with taking on a space software project for the first time, in an academic environment. Given this, it is interesting to note that the missions launched to-date with FSDK-developed software have primarily been commercial, as opposed to academic, student-led missions. A review of existing literature to establish what then is being used for other missions suggests that both industry and university CubeSat teams are commonly opting for full in-house development of flight software for the reasons stated within this work (i.e. development of knowledge/skills, flexibility, freer reusability, cost and available resources). Open-source materials are used by these teams to help their development. This includes using the options mentioned in Section II as reference models, but also involves using widely-used code and tools (e.g. using a Linux operating system [12, 13]), which generally relates to the level of support available from the community, as well as available documentation on coding, software design and development standards (e.g. using the IEEE Standard 1016 software design document [14]). Nevertheless, expanding on the points made in Section V, it is worth noting that CubeSat teams which opt for open-source development also face some unpredictable risks (e.g. added costs - while the general software product may be free, good quality support, documentation, bug-fixing, etc. may not). For these projects, the modular software architecture resulting from CBD is very popular for developing maintainable and extensible flight software. Other modular development approaches used by CubeSat teams include agile software development and service-oriented architecture engineering [12, 14].

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Student perspective and lessons learned from participating in ESA ESEO mission

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Abstract—**In this paper we would like to present what we have learnt by participating in the ESA's European Student Earth Orbiter (ESEO) mission which is an educational satellite program. We gained hands-on experience by manufacturing, adjusting and testing the components of the Power Distribution Unit (PDU) subsystem and the Langmuir Probe experiment (LMP). ESA provided the opportunity to participate in courses organized by ESA Academy. At the last phase of the preparation we visited Sitael S.p.A. in Forli for the final testing of our modules before assembly, where we could work together with Sitael's experts in a space industry grade environment. The Assembly Integration and Testing (AIT) workshop in ESTEC provided great educational value for all of the LMP and PDU team members.**

Keywords— ESEO, ESA, Academy, student satellite, BME team, hand-on experience, career

I. ESEO Mission

The European Student Earth Orbiter is an educational micro satellite project for university students. Ten Universities from eight ESA Member States have participated in ESEO with more than 600 university students involved in the project. The educational objective of the project is to give hands-on experience of a real space mission for university students in order to prepare a well-qualified technical workforce for the European space sector. The students were responsible for developing and testing the payload (scientific instruments or technology demonstration experiments), key satellite subsystems and the ground segment to the mission. Besides the educational purposes, ESEO has objectives during its 6 months long operational mission phase such as taking pictures of the Earth's surface, measuring radiation levels and plasma properties on Low Earth Orbit (LEO). Furthermore, testing freshly developed technologies for future ESA small-satellite missions was another purpose of ESEO. By carrying a radio payload, it also enables radio amateurs to establish connections with the spacecraft on VHF band moreover the UHF and S-band ground segment (ground stations and Mission Control Centre) is fully operated by student teams [1].

The ESEO satellite was launched from the Vandenberg Air Force Base in California (US) on 3 December 2018, by a SpaceX Falcon 9 launcher, together with several other micro, nano and pico satellites from all over the world. It was set into LEO within the frame of the Spaceflight's SSO-A: SmallSat Express dedicated rideshare mission [1].

Fig. 1. ESEO model [1]

II. About Our Team

In the past thirteen years many students from Laboratory of Space Technology worked on the ESEO project along with professionals. Our laboratory has a heritage of working on many spacecrafts such as the Philae the lander unit of the Rosetta space probe. The laboratory has a method of involving students, supervised by professionals, in the ongoing projects. The students can gain hands-on experience by taking part in designing, building and testing a spacecraft component.

In the past years many students from the laboratory worked on the ESEO project. Some of them continued their careers in the space industry or stayed at the laboratory as PhD students. The current student team members have joined the ESEO mission three years ago. During this time, we worked on two different parts of the satellite. We also participated in the events organised by ESA Academy to widen our knowledge about the ESEO satellite and other space related projects.

In our laboratory, besides of circuit simulations and modelling, students usually build them on test panels. This is an effective way for students to practice soldering and most importantly, they get a very deep understanding of the device which they build. These models are also good to test most of the functionality and parameters of the circuit.

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Fig. 2. ESEO PDU-EBB2

III. Experiences from PDU

The main objective of the Power Distribution Unit (PDU) is to supply electrical power to the subsystems of the satellite and payloads and to prevent the overload of the main power bus. The unit consists of two identical and connected PCBs called motherboard, in order to provide the required redundancy as one of them is the Main board and the other is the Redundant. In order to manage the power distribution and prevention functions each payload and subsystem has a dedicated Latched Current Limiter (LCL) circuit as daughterboards on the PDU which connects them to the main power bus. Every LCLs has an individual current limit and undervoltage protection level set as referred by the requirements of the payload or the subsystem. The detailed function of the PDU and the LCLs were presented last year at the 2nd Symposium on Space Educational Activities [2].

As students of the laboratory we got involved in the work on the PDU. We could take part in various tasks. One big job was to calibrate each LCL individually to meet the required current and undervoltage classes. Students were responsible for soldering the calibration components into the circuit where they learned the technique of handling and soldering according to the requirements for space grade components. After calibration students carried out the functional, thermal and EMC tests of the PDU and the LCL-s alongside with professionals. During the EMC tests we studied many ESA ECSS standards witch a spacecraft must match [3]. It was the task of the students to prepare the test environment including test boards and other preparations for the measurements.

During this work we got deeper understanding of how this type of current limiter works. We can carry on this experience in our further careers. To mention an example, one of the students wrote his BSc thesis on the potential of further improving this circuit.

IV. Knowledge gained from LMP experiment

The instrument of Langmuir Probe is a scientific experiment which aims to measure the plasma properties in the ionosphere, the upper regions of the atmosphere of Earth. The device can examine the electron temperature, electron density and ion density by obtaining the voltage-current characteristic of the plasma which depends on the parameters mentioned above. From further analysis of this curve, additional scientific results can be achieved such as conclusions on solar activity and plasma anomalies for instance the South Atlantic Anomaly.

The instrument consists of two well separable parts such as the Langmuir Control Box and the Langmuir Detector. Inside the surface treated metallic housing, the device contains three well separated circuitries such as the Amplifier (AMP), the On Board Data Handler (OBDH) and the Power Supply (PS). The Amplifier is responsible for the low signal level measurement of plasma voltage and current, so the precise adjustment of the measuring circuits was necessary during the development. Therefore, we could have an insight to the principles of the low signal level measurements and the complex selection process of proper electrical components. For instance, the temperature independence was an important point so we carried out lots of design and examination in climate chamber to make components more resistive against temperature change. The OBDH is the central data processing unit of the experiment so we could learn a lot about the design of digital circuits such as the PCB design and the operation of the microcontroller which is the heart of the OBDH. The PS unit is the own DC-DC converter of the device. It is a complex flyback converter with eight different outputs therefore during the developing phase we could obtain a lot of knowledge about the design principles of switching-mode power supplies. Moreover, the design and manufacture of unique components such as the flyback transformer have also been done by students.

When the LMP was prepared, several qualification tests were carried out both on the engineering model (LMP-EBB) and on the flight model (LMP-PFM). They were subjected to random and sinusoidal vibration tests, cyclic thermal test with functional examinations on marked temperatures (-25°C, +25°C, +70°C) furthermore conducted and radiated EMC measurements. From this complex test campaign, we could become familiar with the principals and practice of special test methods that are required to qualify instruments for small satellite board.

To evaluate the scientific data provided by LMP, our student team prepared a special software to process and evaluate the information forwarded by the ground station for scientific data in Munich. Therefore, the analysis of the dataflow is possible and required plasma properties would be concluded [4].

V. Training courses by ESA Academy

During the whole lifetime of the program, ESA Academy organised several trainings and workshops for the ESEO student teams. Thus being members of the ESEO-PDU and ESEO-LMP teams, in May and July of 2018, ESA Academy provided us a wonderful and unique opportunity to attend two training courses about Spacecraft Operation and Spacecraft Communication which were held by the staff of Training and Learning Centre in Redu, Belgium. Both events were held by a distinguished tutor who is a member of the ESA operator team in ESOC so we could get lot of first-hand experience from a real professional. We were taught about the principles of operation of the functional parts of a spacecraft such as power, communication or thermal subsystems. We could obtain useful knowledge about establishing communication link with spacecrafts, managing the operation during mission phase with the most efficiency and selecting ground stations to keep in touch with our satellite. Those lectures were very interesting

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Fig. 3. Students at Redu station [1]

because the lecture material was always accompanied with examples and interesting stories from real life experiences.

As an additional program beside the lectures, we had the opportunity to visit the ESA ground station in Redu where we got a full guided tour around the site. We could see the enormous high gain parabolas during operation and we were invited into the operational room where we saw how to transform the learnt principles into practice and where we experienced how real satellite tracking works.

These two training courses were also such great social events because we had the possibility to meet university students from different countries of Europe, with similar fields of interest on space sciences and technologies. We could work together on our own imaginary space mission, so we shared a lot of knowledge and experience and we acted as a real spacecraft operator team which was as interesting as the lectures.

VI. Hands-on experience in Forli

After all units of the satellite had been completed and as the final integration approached, every university team was invited by the prime contractor SITAEL to deliver their own instruments. Furthermore, we had to carry out a final test process in order to obtain the final qualification of being onboard and getting prepared for the platform integration. So in August of 2018, our team was headed to Forli carrying the models of LMP with ourselves. The PDU had been shipped to the prime contractor previously for being an essential part of the Power Subsystem of the satellite. It was required to deliver not only the flight unit but the engineering model, because the EBBs had been assembled into the avionic test bench, called Flatsat, which is a full counterpart of the flight model of ESEO and contains the engineering models of all onboard units.

In Forli, we had the opportunity to test our instruments in real space industrial environment and to get more practice in the use of industrial measurement equipment. This was also a great experience that we were working in a clear room with the help of professionals of SITAEL which collaboration was an outstanding chance to share knowledge with each other. Fortunately, based on the results of the final tests, both of our instruments obtained the qualification to be assembled to the board of ESEO.

Fig. 4. BME team at SITAEL

Although our days were busy with lots of work, we had the honorific invitation of being interviewed by an ESA representative about our parts in the ESEO mission. We could briefly describe our experience about the project, about our instruments and we could share the happiness and excitement about the approaching launch event.

VII. AIT workshop

After the satellite was assembled, ESA Education Office organised the Assembly Integration and Testing (AIT) workshop in Noordwijk. The main purpose of the workshop was to gather all the teams from every participating university so the students and professionals could meet and exchange knowledge that they learned along the way. During the workshop we attended several presentations about the Test Campaign and of the ESEO. We learned about vibration, thermal vacuum and EMC testing carried out by industrial and ESA professionals on the whole satellite.

In one of the breaks, they showed us a special virtual reality program in which we could dissemble the ESEO. This technology could help engineers of the future to work together in a virtual laboratory on life-size 3D model even if they are in different countries.

Fig. 5. Group picture of the AIT Workshop [1]

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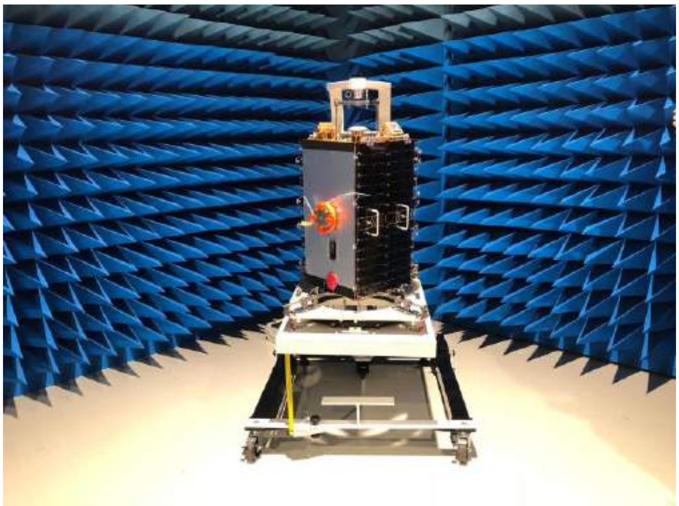

Fig. 6. Complete ESEO satellite [1]

We also visited the ESA's space research and technology centre, ESTEC. We had the opportunity to get a glimpse into different sites of the establishment where the ESEO was tested for example we could get a sight into the anechoic chamber. At each place, we got a brief description of a way how different tests were conducted on the student satellite. The best experience of our visit was when we saw the fully integrated ESEO, the result of the hard work of many universities

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VIII. SUMMARY

The ESEO satellite was a great opportunity for everyone who worked on this project to gain invaluable hands-on experience in space technology. We benefited from working with university and ESA professionals and from participating in the courses and workshops organised by ESA Academy. We also got to know other university students and professionals on social events and team projects during these courses. From these opportunities, we enriched with many useful knowledge and experiences and established new relationships with fellow students. All these knowledges will be a huge help in our future careers. We are very grateful to ESA Academy for the ESEO project and for the educational programs which came with it.

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Development and Testing of a Poly-Finger Gripper for a Planetary Rover in the Fields of Science and Study

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***Abstract*—This paper describes the design of an end-effector system suited for a mars analogue mission. In the scope of a bachelors thesis, a cost-effective, lightweight and robust gripper system was developed. The system was successfully tested and verified. It will be used on a mobile robotic platform for educational and research purposes.**

***Keywords*—rover; space robotics; gripper; cost-effective; open source; open hardware;European Rover Challenge; Mars analogue**

I. Introduction

In the fields of space exploration, robotic systems are indispensable. Rovers utilize end-effectors to interact with their surroundings, manipulate objects or take samples. This paper elaborates an end-effector system suited for a mission scenario derived from the European Rover Challenge 2018 [1]. The BEAR Gripper offers a high grade of versatility and is inspired by anthropomorphic mechanisms of the human hand. It was designed, manufactured and tested at the Technische Universität Berlin. At the current time, it is used on the Bear Exploration and Assistant Rover (BEAR). A cost-effective, lightweight and robust gripper system was developed in the scope of a Bachelor's thesis. The ERC mission scenario served as a realistic application frame.The event focuses on robotic systems developed by students and puts them to the test, under simulated surface conditions of a foreign planetary body. In 2018, a Mars analogueenvironment was chosen as the scenario. They are best described as corresponding to assist service tasks for a manned exploration mission. These include the manipulation of a terminal by turning knobs and switches into specified positions, grasping cylindrical cache containers and obtaining various soil samples. A gripper system by OpenBionics [2] served as inspiration. Keeping the bioinspired grasping mechanism in mind, the BEAR Gripper finds a remastered way to implement an underactuated gripper system. Three fingers with two joints each are realized. They are actuated by a single servo motor [3] via a combination of steel strings and springs. Novelty lies in the implemented joint design which unites the joints and the guidance system for the steel strings. A differential mechanism prevents the fingers from any uncertainties of force application. Furthermore, it enables them to individually grasp around irregular shaped objects without dedicated commands. The gripper can be changed between a cylindrical and a spherical grasping pattern by rotating two of the fingers into an opposing orientation. The system was successfully tested and verified in all tasks. The design of the whole system is planned to be released as an open hardware design soon.

II. Development Breakdown

The BEAR Gripper was designed regarding its requirements for the numerous tasks in the given mission scenario. By analyzing the given requirements and estimating boundary conditions, five concepts have been considered. Concepts featuring cylindrical and spherical grasping patterns were compared along with configurations of two fingers up to four fingers. These concepts were evaluated using Multi-Attribute-Utility [4].This method was applied on each mission scenario separately, resulting in the present three finger design with a hybrid grasping pattern. Via rapid prototyping and the principles of lightweight design commonly used in the aerospace industry [5], the design was improved iteratively. Physical properties like kinematics and dynamics were determined by calculus in mechanics and implementing into computer simulation. Stress and reliability estimations were made analytically and later tested. Most of the system was manufactured and assembled at the department's workshop. The testing took place under laboratory conditions. Therefore, each mission was simulated and success criteria had to be achieved.

III. Detailed Design

The anthropomorphic approach leads to the use of strings for mimicking tendons form a human hand. Thus, strings are attached at the end of each finger which are guided with pulleys through the phalanges and the rest of the gripper's casing to the actuator. The actuator is the Dynamixel MX-64 servo motor [3], which pulls the strings in or releases them. In this way, the strings are shortened and due to geometric constrains the fingers bend. This is an underactuated process

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since only one actuator operates two degrees of freedom of each finger. If one finger is blocked, a differential connecting all finger strings allows the other fingers to continue their movement, ultimately succeeding in the grasping process. This is a versatile principal to grasp numerous objects from different shapes without the need of pre-programmed grasping patterns or specialized finger shapes. It can adapt to a variety of surface geometries. To minimize and simplify the precision mechanics, the hinges of the joints simultaneously serve as guiding pulleys for the steel strings. With a pulley placed into the geometrical rotation axis of the hinge, no secondary pulleys are needed to guide the strings around the joints or align them afterwards. Additionally, the string's exposure to the open environment is reduced so no obstacle can harm (or even cut) them by direct contact over the grasping process. Fig. 1 shows the CAD of the finger with all its features.

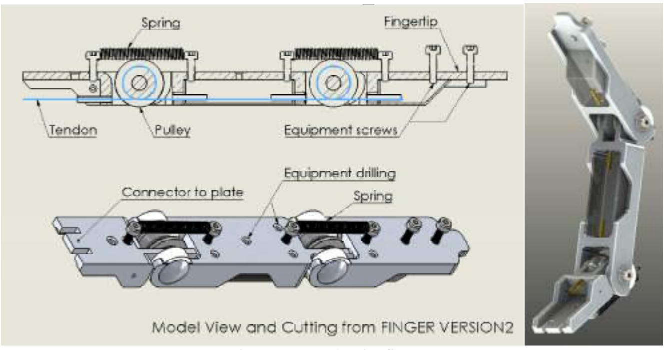

Figure 1: Robotic finger

The mechanism to open the actuated finger was implemented by springs on the outside of the finger. Contracting a finger builds up a certain spring force which pulls the phalanges back into the open starting position. The whole assembly is shown in Fig. 2. An acryl glass window allows an inside view onto the servo motor and the string guiding system.

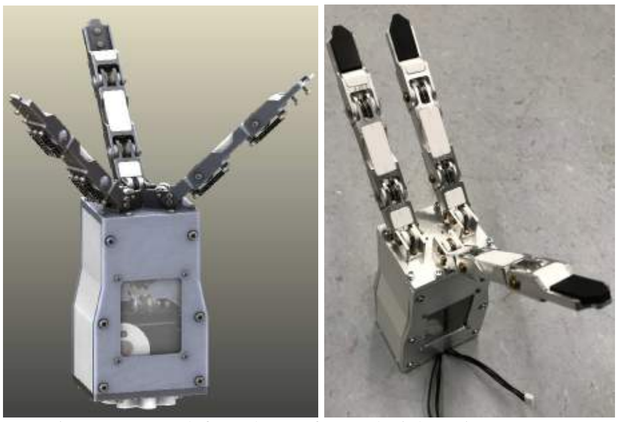
Figure 2: CAD (left) and manufactured (right) gripper system

IV. TESTING AND FUTURE STRATEGY

Multiple experiments following the three Field Test scenarios from the ERC were conducted to prove the performance and show potential limits of the gripper. For controlling the servo motor, the software Robotis R+ Manager was utilized [7].In the scope of the Collection Task, special cache cylinders and containers should be grasped and stored. This was successfully done with replicas. The Maintenance Task posed the challenge to operate switches and knobs on a terminal interface which was ergonomically designed for humans. The tests were conducted on a terminal mockup. All interfaces could be operated. The Science Task required gathering of soil samples and subsequently storing them. For this scenario, three types of sand were used differing in their granularity. The gripper was equipped with also developed shovel attachments for the fingers. Fig. 3 displays the BEAR gripper performing and passing all three different tests without any major issues or failures.

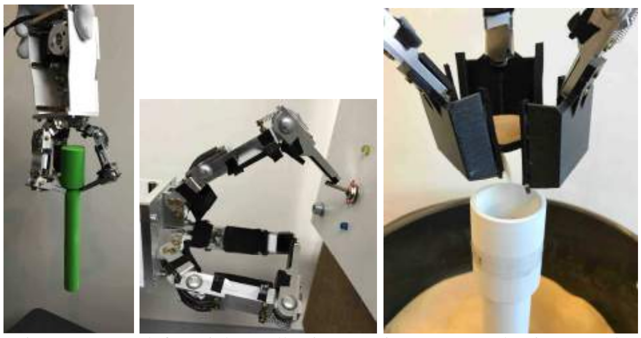
Figure 3: From left to right: Collecting-, Maintenance- and Science Task

After testing, a series of remarks arose. Getting a solid hold on small objects was difficult. Rubber strips on the fingers could increase the grip on smooth surfaces. Additionally, the differential prevented the system of building up static holding force equally for each finger. Maintaining a specific position for one stressed finger was not possible. Since the MX-64 provides a very high stall torque (6 Nm) there still is potential for performance increase. By upgrading the steel strings' thickness or material with similar tensile strength, the maximum torque could be increased. Additionally, the counteracting springs at the fingers' outsides can be replaced by versions with a higher stiffness. This would stabilize the whole opening and closing procedure and could provide a greater static force output for the fingers. A rather large upgrade consists of the implementation of a second actuator mechanism to rotate the two fingers remotely.

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Space Academy: A Journey from Hospital to Mars

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Abstract— **Being in hospital can be a very frightening and lonely experience, especially as a child and especially when in an isolation unit. A patient may be in isolation either because they are infectious to other patients or because they are immunosuppressed, and it is dangerous for them to be around other patients and illnesses. Edinburgh Children's Hospital Charity (ECHC) is developing a Space Academy programme which aims to take the isolation experienced by these children and mirror it with the experience of an astronaut in space, thereby using the idea of space exploration to inspire children who are at their most vulnerable, and hopefully lessen the negative impact hospital experiences may have on a child. ECHC's Space Academy is a 3-week programme which sees each child through the stages of their mission to Mars, right through from pre-launch to debrief. A video-guided app is being developed to take them through their journey, with Tim Peake having agreed to record the introductory video. Each day offers different activities which follow this narrative, and which have been developed to abide by infection control restrictions within the hospital environment. Many of these activities are designed to parallel the work of scientists and astronauts, having used ESA resources aimed at school teachers as a guideline. The programme will therefore provide the children and young people with a way to engage with science whilst in hospital, at a time when they may be missing out on mainstream education. The programme is due to be trialled in the oncology ward of the Edinburgh Royal Hospital for Sick Children in 2020, since many cancer treatments result in a lowered immune system which requires the patients to be in isolation. This paper outlines the need for such a programme, the details of the planned pilot initiative and discusses the potential future development and reach of the project.**

Keywords—space, Mars, clinical isolation, hospital, STEM, STEAM

I. Introduction

Clinical, or 'source', isolation refers to the increased infection control measures that are put in place when a patient is highly contagious to others, or when they are immunosuppressed and therefore highly susceptible to infection. In such cases, each patient resides in a 1-person isolation cubicle to minimise the spread of infection. Although isolation is necessary for many patients and may be considered beneficial for the quiet and privacy provided, there is much evidence to suggest that clinical isolation results in higher levels of stress, anxiety and depression for patients [1]. This is almost certainly a consequence of the feelings of abandonment, loneliness, neglect and boredom that these patients experience [1,2]. This, together with their lowered self-esteem and sense of control, affects these individuals' ability to cope with their situation [3].

Very little research has been done into the impact of clinical isolation on the mental health of children and young people, and how this impact may be lessened. Due to the strict infection control regulations that are in place to minimise the bacteria that can enter and leave each cubicle, it is especially difficult to cater to the non-clinical needs of these children and young people. All things entering the room need to be brand new or be able to be cleaned using disinfectant wipes. Soft toys, board games and arts materials are all seen as bacterial breeding-grounds by clinical staff. It is also required that any staff entering the room first needs to don a plastic apron and thoroughly wash their hands. Therefore, there is an increased need for creativity when trying to meet these non-clinical needs.

Play specialists at the Royal Hospital for Sick Children (RHSC) in Edinburgh consulted patients who have had experience of clinical isolation for ideas on how the experience could be improved. One of the children likened being in isolation to being an astronaut, and the idea took off from there. Staff at Edinburgh Children's Hospital Charity (ECHC) have put together 'Space Academy' – a programme of activities which aims to combat the social isolation, lack of control and boredom that these children and young people experience, whilst abiding by infection control regulations, with the overarching theme of space travel. The project uses STEAM-based activities in order to help participants feel part of a wider project and community, allow them to engage with fun, educational material and provide them with the ability to transform their forced environment.

This paper explores the potential role that STEM education, together with artistic expression, could have in combating the negative effects of clinical isolation. An outline is provided of the motivation behind the project, the structure of the 3-week programme which is due to be trialled in the RHSC in 2020, and the future development and potential of the project.

II. From Hospital to Mars

Upon consulting Romain Charles, an ESA member of the 520-day isolation crew of the Mars500 mission, it became clear just how many parallels could be made between the life of an astronaut and the lives of the children and young people in clinical isolation. The regimented schedule that members followed during Mars500, which is of a similar structure to that of ISS astronauts, is comparable to the routine that hospital patients follow. According to Mr. Charles, an average day on Mars500 would follow a schedule similar to:

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- 08:00 – Medical checks (weight, blood pressure, ECG, etc.)
- 08:30 – Breakfast
- 09:00 – Work (experiments)
- 12:30 – Lunch
- 13:30 – Physical exercise
- 14:00 – Complete experiments from earlier in the day if necessary, read/write emails to friends and family, improve Russian
- 18:00 – Dinner
- 19:00 onwards – Common activities e.g. games console, tv

The routine medical tests, strict meal times (with a limited, repetitive menu) and restricted contact with friends and family are all aspects of daily life in clinical isolation. Though these similarities are at the core of the Space Academy project, it was necessary to bear in mind one important difference throughout its development – astronauts choose to go into space and are able to physically and mentally prepare themselves for it; these children and young people do not choose to be in hospital.

From there, it became about developing a mission plan – a story that had tangible goals that could be achieved by participants within a relatively short space of time, and that would allow for a coherent range of space-themed STEM topics to be explored. A journey to Mars seemed the obvious choice due to the presence of Mars exploration ambitions in the media currently which provided a lot of scope for potential activities. The 'astronauts' (participants) start their journey with a *Pre-Launch* introduction to the programme. They then go through *Launch*, a 'visit' to the *International Space Station*, *Life in Space* and *Mars* before their *Return to Earth*, all with the overarching mission of Mars exploration. At its core, the journey makes a parallel to the experience of a patient – being in an unfamiliar setting surrounded by alien technology until the hopeful return home. However, due to the unfortunate fact that not all participants will reach this part of their own journey, this theme has only a subtle presence.

The storyline of a journey to Mars also allows for STEAM subjects to be explored in an unconventional way which aims to capture the imagination of participants. The patients in isolation are often there for extended periods of time and, as such, miss out on large portions of their schooling. At the RHSC in Edinburgh, patients expected to be in hospital for more than five nights are automatically offered teaching (which they can choose to engage with depending on how they are feeling each day). However, there are only two teachers for a hospital with roughly 100 bed spaces. This, together with the additional restrictions associated with teaching children and young people in isolation, both limits the time spent learning and the subjects that they are able to engage with, since English and maths are prioritised by NHS teaching staff. Therefore, a programme which allows patients to engage with educational STEM material, in a way which encourages creativity, would be an innovative resource for combating the immense boredom that these patients face.

Each phase of the journey includes activities which relate to that phase. Several of these activities encourage participants to transform their cubicle into a space-themed haven, therefore giving them the ability to impact their forced environment. Research suggests that the best way of minimising the negative impact clinical isolation can have is to provide patients with a sense of control [3].

Though the activities are mainly designed to be enjoyable, there is also an opportunity for self-led learning. It was decided that a programme consisting of short daily activities over 3 weeks would be of suitable length to achieve tangible goals whilst remaining interesting for participants. The programme is designed to be flexible to the child/young person so that they are able to pick it up and put it down depending on when they feel up to it, and so they can tailor the experience to what interests them. None of the activities are compulsory and participants do not have to stick to the proposed structure. There is also the option during each activity to go into varying levels of theoretical detail depending on the age and interests of the child/young person.

III. The Space Academy Programme

The 3-week pilot programme that has been devised by ECHC follows a 'journey to Mars'. It is due to be trialled in the oncology and haematology ward of the RHSC in 2020 since many of the patients in this ward become immunosuppressed due to their treatment and therefore are required to be in clinical isolation.

An app and logbook are being developed to accompany the programme which will allow participants to reflect upon their experiences. The app will guide the participants through each day of their journey, with an introductory video from Tim Peake to brief the 'astronauts' of their mission. The app will include instructions for each of the daily activities, fun facts and information about their 'crew' (doctors, nurses and play specialists). Each participant will have their own digital tablet whilst in hospital which will allow access to the app and provide them with a platform to complete certain activities.

Pre-Launch will include the welcome from Tim Peake and will aim to prepare the participants for their journey into space. The participants will get the chance to add to their own profile which will include their likes and dislikes, their mission badge (that they will have the opportunity to design) and their very own flight playlist (like ISS astronauts have for their launch days). Other pre-launch topics and activities include spacecraft materials testing, a captain's checklist, rocket design and 3D printing, and aerodynamics.

After lessons on how to count down in various languages (to emphasise the presence of many nationalities aboard the ISS), a video will play on the app which shows lift off from the RHSC, hence concluding the Launch phase of the mission.

The participants will then find themselves aboard the International Space Station, where they will complete activities to further understand life on Earth and in space. These

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activities will involve experimenting with gravity, delayed communications with Earth, and a robotic arm. Aboard the ISS, participants will have their first opportunity to feed back to 'Mission Control' (their school). This offers participants the chance to engage with their peers and feel part of a wider project and community, whilst also providing their peers an insight into, and understanding of, their hospital experience. It is hoped that this will lessen the extent of their social isolation and make the transition back into school a less daunting experience. Many of the activities completed during the ISS phase of the mission were adapted from ESA's ISS Education Kit for teachers.

The journey from the ISS to Mars is encapsulated in the Life in Space section. The participants will learn all about their solar system and of the constellations that can be seen from within it. This will involve learning about the Sun, and the electromagnetic radiation that it emits.

Once on Mars, participants are challenged to build a rover to help investigate whether life has ever been sustained on Mars. ECHC are working in collaboration with Airbus, Centre for Life, ESA, ESERO, and UKSA to develop a Mars Challenge which is envisaged to engage 50,000 people in space educational activities. As such, the Mars section of ECHC's Space Academy will consist of activities and materials designed for the wider project, making the necessary adaptations for use in the hospital environment. During this phase of the mission, participants are encouraged to consider what would be needed to sustain a civilisation on Mars, asking questions like: should there be a monarchy on Mars? If so, who would be on the throne?

Upon arrival back to Earth, the participants will be debriefed on their mission to Mars and will be encouraged to reflect on the contents of their logbook. All participants of Space Academy will be awarded a personalised certificate, regardless of whether they have completed one day or twenty-one days of the programme. The reality of the hospital environment may mean that few participants actually complete their Space Academy journey – whether that be due to early discharge, or constraints set by how well or unwell they may feel at the time – which is why it is important to reinforce their achievement no matter what stage has been reached. The app will also award participants with digital badges when activities and sections that are completed to reinforce this sense of achievement.

IV. Testing

With two or three activities having been assigned to each day, it was important to ensure the activities are fun, engaging and accessible to multiple age groups during development. Meeting these criteria is made all the more difficult by the strict infection control regulations within the hospital. Several of the activities have been trialled around the wards of the RHSC, as well as at ECHC's youth group for 12-18 year-olds, to ensure these criteria have been met. The response from patients, staff and parents/carers to the activities was very positive. One patient in particular vocalised the benefit of such activities for children and young people that miss out on large amounts of mainstream education as a result of being in hospital. The young person was very interested in the theory behind the activities, since he had missed out on the science that would have been covered in school whilst undergoing numerous rounds of chemotherapy. That said, the same activities were also enjoyed by many others, including two siblings (aged 4 and 6 years old) who were in the hospital visiting their sister.

Most activities were accessible to the suitable age range, since it was ensured that the underlying science/theory was not key to being able to engage with the activity. That way, the children and young people participating in these activities could take as much as they wanted from the experience. Trialling the activities in this way ensured that the programme and app were developed in such a way as to ensure participants can engage with varying levels of information and therefore reinforce that the programme is meeting the needs of children and young people of various ages.

V. Conclusion and Future Development

It is evident from research and recorded patient experiences at the RHSC in Edinburgh that there is a need to better accommodate the non-medical needs of children and young people admitted to clinical isolation. Staff at ECHC have developed the Space Academy programme in hope of achieving this through using STEM-based activities – in an unconventional, creative way – to lessen the negative impact that clinical isolation can have.

Trialling the project in the oncology and haematology ward of the RHSC will allow for any teething problems to be ironed out, and feedback to be gathered from participants. After such a time, the programme will be made available to all children and young people admitted to clinical isolation at the RHSC. Should other hospitals then show interest in the project, it would be reasonably simple to share the materials since the only part of the programme specific to Edinburgh is a short video clip where the participants 'take off' from Earth and leave the RHSC.

More than 150 children and young people are admitted to clinical isolation in Edinburgh alone. Space Academy is the first project of its kind which attempts to improve this experience.

Acknowledgments

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3rd Symposium on Space Educational Activities, September 16-18, 2019, Leicester, United Kingdom

Design and development of a 1-axis attitude control testbed for functional testing of EIRSAT-1

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***Abstract*— The performance of the Attitude Determination and Control Subsystem (ADCS) of a CubeSat relies on consistent and robust inputs from sensors to provide the actuation to manoeuvre and stabilise the satellite orientation in space. This paper details the design and manufacture of a 1-axis motorised testbed to perform pre-flight ADCS functional testing of a nanosatellite based on the CubeSat Standard. This testbed has been developed to support the Educational Irish Research Satellite, EIRSAT-1, a 2U CubeSat being developed in University College Dublin (UCD) as part of the European Space Agency (ESA) Fly Your Satellite! (FYS!) Programme. EIRSAT-1 is a student led project to develop, build, test and launch Ireland's first satellite. The project is a collaborative effort of staff and students across a range of disciplines including physics, engineering and maths.**

The design of the testbed allows all axes of the CubeSat to be tested individually. The design can be adapted easily to accommodate individual subsystem boards, such as an ADCS motherboard, in addition to larger CubeSat sizes, thus making it applicable to other missions. This testbed will be used to fully assess the functionality of the EIRSAT-1 ADCS motherboard, its inertial measurement unit, sun sensors, and magnetorquer actuation, first testing the Engineering Qualification Model (EQM) and then the Flight Model (FM). The testbed allows for polarity and performance checks of the sensors by comparison with known good reference sensor values. A controllable motorised rotating testbed allows for automated testing of the gyroscope and magnetometer. The performance of the five magnetorquers required for actuation is evaluated by an external magnetometer for each actuator. An easily adjustable artificial sun source allows for characterisation of the fine and coarse sun sensors response to change in angle relative to source. The testbed allows the satellite sensor and actuator outputs to be compared pre and post test procedures including ambient, vibrational and environmental test campaigns, in order to confirm full functionality or clearly indicate any issues.

Keywords— CubeSat, Attitude determination and control, Fly Your Satellite, EIRSAT-1

I. INTRODUCTION

The attitude determination and control subsystem of a satellite obtains the satellite's orientation in space and is responsible for spacecraft pointing. It is a challenge to verify this subsystem due to its numerous components and the complicated task of accurately recreating the space environment.

The attitude control subsystem of a satellite has three main components; the sensors, the actuators and the determination and control algorithm. Data from a suite of sensors is input into the attitude controller which runs an algorithm that fuses these sensor inputs together to determine the best estimate of the satellite's orientation. If the orientation of the satellite needs to be changed, the control system calculates the commands to send to the actuators to obtain the desired new orientation in space. Clyde Space Ltd. (CS) are providing the ADCS hardware for EIRSAT-1, as well as a bespoke ADCS algorithm which is currently under development and is expected to be delivered in September 2019. Therefore, the work presented is focused on validating only hardware components of the ADCS subsystem of EIRSAT-1.

This paper will outline the educational process of designing a versatile single axis testbed to verify that the individual components of the attitude control subsystem of EIRSAT-1 are functional and to assess their performance. The design requirements included that the testbed can be modified to include other CubeSats from 1U to 3U and be relatively low-cost and robust, allowing for each axis of EIRSAT-1 to be tested in turn.

II. EIRSAT-1

A. Mission Overview

EIRSAT-1 is a 2U CubeSat (10cm x 10cm x 22.7cm) being built in UCD as part of the ESA FYS! Programme. It is a student led project with students taking leadership roles including management of subsystems and payloads.

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The EIRSAT-1 project is driven by educational objectives to enable Irish students to gain sought-after skills for the space sector, foster collaboration with industry and inspire future generations in space science and engineering [1].

EIRSAT-1 consists of conventional CubeSat subsystems such as an On-Board Computer, Communications module, ADCS and an Electrical Power Subsystem (EPS) [2]. The EPS consists of four solar panels on the +X, +Y, -X and -Y faces of the satellite [2], the EPS motherboard and battery. All of these are being procured as 'commercial-off-the-shelf' (COTS) components from Clyde Space Ltd. In addition to these subsystems, three novel experiments will be flown on EIRSAT-1, the Gamma-ray MODule (GMOD), the ENBIO MODule (EMOD) and Wave Based Control (WBC) [2].

B. *Experimental Payloads*

Gamma-ray Module: GMOD is a bespoke gamma-ray detector being designed and built in UCD. During the mission lifetime of EIRSAT-1 it will study Gamma-ray Bursts, high energy explosive events due to a neutron star merger event or the death of a massive star. GMOD is based on technologies that have been developed in UCD as part of previous work funded by ESA [3]. GMOD is expected to detect approximately 20 GRBs a year above a 10σ threshold [2].

ENBIO Module: EIRSAT-1 is working in collaboration with the Irish company ENBIO Ltd. on the ENBIO Module. On the +Z face of EIRSAT-1, there will be four thermal coupons, two will have an ENBIO Ltd. SolarWhite spacecraft surface treatment and the other two will be treated with SolarBlack. EIRSAT-1 will conduct in-flight performance monitoring of these thermal barrier coatings [2].

Wave Based Control: Wave Based Control is the third experiment on-board EIRSAT-1. It is a novel attitude control algorithm for flexible subsystems that has been developed in UCD. WBC has been tested extensively in a simulation environment but EIRSAT-1 will provide the first in space test of this algorithm [4].

III. ATTITUDE DETERMINATION AND CONTROL SUBSYSTEM OF EIRSAT-1

A. *Overview*

The ADCS of EIRSAT-1, hereafter ADCS, will be responsible for detumbling the satellite post deployment from the International Space Station and achieving stable pointing. The pointing direction of EIRSAT-1 is vital for charging the battery via the four solar panels while ensuring there is enough sunlight incident on the four EMOD thermal coupons. EIRSAT-1 will be spin stabilised about the z-axis with an angle of 58° away from the sun and 90° from Celestial North. The ADCS Motherboard (MB) provided by Clyde Space Ltd. will have a specific mode and state which will host the algorithm that will ensure these pointing requirements are fulfilled throughout the mission. The ADCS consists of the following components: ADCS Motherboard, two 3-axis magnetometers (MTM), one 3-axis gyroscope, five coarse sun sensors (CSS), one fine sun sensor (FSS), GPS and the five magnetorquer (MTQ) actuators. The location and function of each of the ADCS components are presented in Table 1.

The 1-D testbed design is required to take into consideration these different components of the attitude control subsystem and determine a method of testing the basic functionality of the suite of sensors and set of magnetic actuators.

ADCS Component	Quantity	Location	Function
ADCS MB	1	PCB Stack of EIRSAT-1	Record sensor values and use in attitude control algorithm to point satellite via magnetic actuators
MTQ	5	+X, +Y, -X,-Y Solar panels, Z-axis MTQ in PCB stack	Actuators to change attitude of EIRSAT-1
FSS	1	+Z face of EIRSAT-1	Provide two sun angles for attitude control algorithm
CSS	5	+X, +Y, -X,-Y Solar panels, -Z face	Coarse position of sun via increase in analog output when illuminated
GPS	1	+X face of satellite	Time and satellite position
3-axis MTM	2	ADCS MB	Provide readings of local magnetic field to ADCS MB
3-axis Gyroscope	1	ADCS MB	Provide angular velocity to ADCS MB

Table 1: Components of EIRSAT-1 ADCS

The electrical specifications of the ADCS MB require a 5V and 3.3V power supply to be provided. The 5V bus is expected to draw 90mA if the MTQs are not driven and the 3.3V bus is expected to draw ≤ 1mA [5]. These requirements and the dimensional specifications of the ADCS MB were important to consider for the mounting of a single PCB to the single-axis testbed.

B. *I2C Communication Protocol*

As part of the software development for the testbed, it was essential to account for the communication protocol of the ADCS MB. The ADCS MB communicates via I2C. The OBC or operating computer is the master and the ADCS MB is the slave with address 0x41 [5]. In addition to providing power, two wires are required for communication, the I2C Data line and the I2C Clock. The ADCS MB provided by CS contains two features to make the I2C communication more robust and mitigate the effects of radiation damage due to single event upsets such as cosmic ray interacting with the ADCS MB.

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Each time a register on the ADCS MB is written to, an 8-bit address hash (AHS) must be provided. If the AHS does not match that of the field being written to, then no data will be written to that memory location. Between the AHS and data being written to the field there is an 8-bit Forward Error Correction (FEC) field. Bits 7 and 6 are used to indicate if the FEC field is in use, and bits 5 to 0 are obtained using an error correcting linear code which must be calculated using the specific data that is being sent [5]. This code can be used to ensure that the data being received from the ADCS MB has not been corrupted.

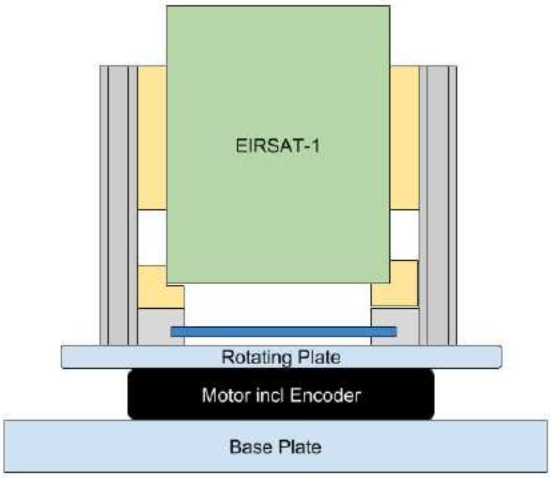

Fig. 1. Initial design concept for single axis testbed based on aluminium extrusions and 3D printed supports

The CS Interface Control Document for the ADCS MB also contains a set of conversion equations [5]. These equations need to be implemented in the software to transform the raw outputs from the ADCS MB sensors and actuators into physical units.

IV. Single Axis Testbed Design

A. Design Requirements

The single axis testbed requirements are governed by the ADCS components of EIRSAT-1 while also allowing versatility in the design for future use. In order to assess the ADCS MB, EQM and FM [6], the testbed had to fulfil the following:

- Allow motorised rotation about 1-axis with control of angular velocity and position
- Provide a method of monitoring the rotational rate of the testbed for comparison with the on-board gyroscope
- Support EIRSAT-1 in horizontal and vertical orientation and support single PCBs of a CubeSat Standard
- Incorporate reference magnetometers for comparison with the two MTMs on the ADCS MB and to assess the five magnetorquer actuators
- Possess a fake sun source mounted to illuminate CSS and FSS from different orientations to test the sun sensors

B. Design Outline

In Fig 1, the main hardware components of the single axis testbed are presented. A motor is secured to a baseplate and then a second plate is attached on top of the motor to hold the equipment being tested. To ensure compatibility with different orientations of EIRSAT-1 and even future missions of 1U to 3U standards, a versatile mounting structure on the rotating plate was designed.

Aluminum extrusion is mounted directly to the rotating plate to provide the main structure. The yellow components in Fig 1 present the initial concept of the 3D printed plastic extrusions to be in contact with any flight hardware and allow for versatility in the mounting of hardware components to the testbed. Currently plastic extrusions for the vertical support of EIRSAT-1, as in Fig 2, the horizontal support and for solely the ADCS MB have been designed and successfully printed. These components were printed in nylon as it is low cost and has a lower coefficient of friction than the conventional 3D printer material, Polylactic Acid (PLA).

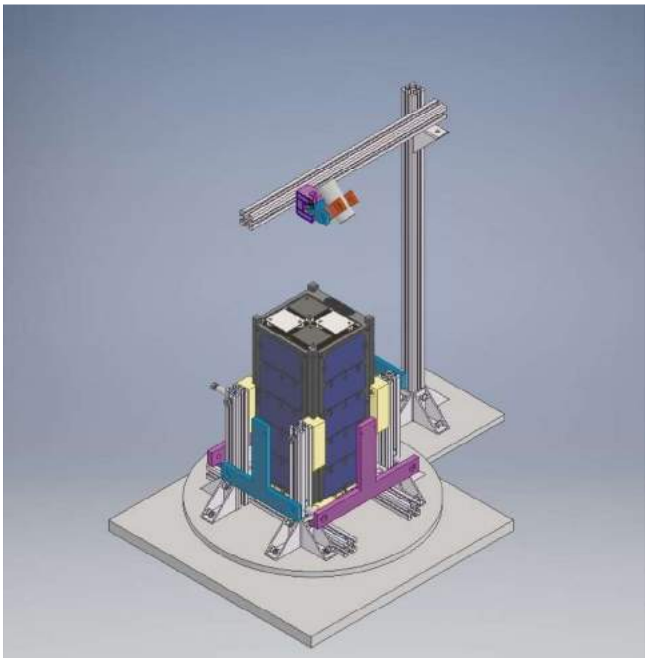

Fig. 2. Final CAD model for single axis testbed including rotating testbed and sun source support structure

Additional components were added to the testbed design to test the different sensors and actuators that comprise the EIRSAT-1 attitude control subsystem. Fig 2 presents the final Computer Aided Design (CAD) model for the single axis testbed

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including the final design for the support stand for the sun source mimic. To allow for testing of the magnetorquers on each face of the satellite and the magnetometers on the ADCS MB, five reference magnetometers are mounted on the testbed. An encoder was selected to measure the angular velocity of the motor for comparison with the ADCS MB gyroscope. In addition to the single axis testbed, a separate sun source mimic support stand was designed to facilitate the testing of the five coarse sun sensors on board EIRSAT-1 and the fine sun sensor on the +Z face.

The iFlight iPower Motor GBM110-150T was selected for the single axis testbed to provide a low maintenance and high durability motor. This motor put constraints on the design of the testbed. The base plate and rotating plate are mounted directly to the motor as it has four mounting screw holes on its base and eight on its upper face. The motor also accommodates a 12-wire slip ring allowing for 5V, 3.3V and GND to be connected to the ADCS MB or satellite, as well as the clock and data lines for the I2C bus communication. The motor controller procured for the testbed was the Odrive V3.5 [7] as it is a versatile controller that is suitable for brushless DC motor control and has open source hardware and software. The Odrive motor controller supports many interfaces including USB to computer or Raspberry Pi and UART to Arduino, both of which were used during the development of the testbed. The Odrive has support for a set of encoders that can be used alongside the motor. This governed the selection of the encoder for the testbed.

The encoder selected to measure the angular velocity of the motor was the AS5047P on-axis magnetic rotary encoder with a resolution of 4000 steps or 1000 pulses per revolution meaning an angular resolution of 0.09° [8].

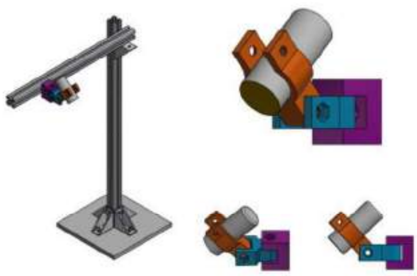

Fig.3 Left: Sun source mimic support stand. Right: Three 3D printed components for wide range of incident angles of sun mimic on sun sensors

The other electronic hardware of the testbed was based on the Grove System which dictated the choice of reference magnetometer [9]. The Grove system is a connector prototyping scheme for simple connection and modification of sensors to a base microprocessor. An Arduino UNO obtains readings from five Grove 3-axis Digital Compass Units which each host a BOSCH BMM150 Three-axis Geomagnetic Sensor. An Adafruit I2C multiplexer is required as all the devices have the same I2C address [10]. A specific byte commands the I2C Multiplexer to communicate to the corresponding sensor, so only one MTM can be communicated with at a time, but as the ADCS MB only updates the sensor values at 1Hz, this does not impact the comparison of the reference MTMs to the ADCS MB sensors.

The final set of sensors that need to be tested as part of the EIRSAT-1 ADCS are the sun sensors. In order to determine the functionality and performance of the five coarse sun sensors and one fine sun sensor on-board EIRSAT-1, a sun source mimic is required. Clyde Space Ltd. uses the Fenix LD20 in their test procedures for sun sensors [11]. As the LD20 was decomissioned, the upgraded model LD22 was purchased as it has similar properities to the LD20. To ensure the light output from the torch is constent during testing the battery powered device was converted to AC power including a switch.

A stand from aluminium extrusion was designed to support a 3D printed device to allow for a wide range of angles of incidence of the torch beam on the faces of the sun sensors on board the satellite. As in Fig 3, a combination of three components were used to allow for movement in two axes and nylon screws were used to secure the clamp components.

V. Results

A. Preliminary Design Assessment

After the full assembly of the testbed, as in Fig. 4, some preliminary assessment was conducted to determine its performance capabilities.

Fig.4. Assembled single axis testbed with sun support stand

The testbed design successfully fulfilled the initial requirements. The testbed allows for motorised rotation of a CubeSat or CubeSat Standard PCB about an individual axis. The concept of having 3D printed nylon components in contact with the flight hardware has resulted in a highly versatile design

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which can accommodate single boards and can be modified for 1U to 3U satellites. The encoder mounted under the motor allows for the rotational velocity of the motor to be measured for comparison with the ADCS MB gyroscope. The five reference magnetometers allow for analysis of the two magnetometers on the ADCS MB and the five magnetorquer actuators. Furthermore, the sun source support stand constructed as in Fig 3 facilitates the assessment of the coarse and fine sun sensors on board EIRSAT-1.

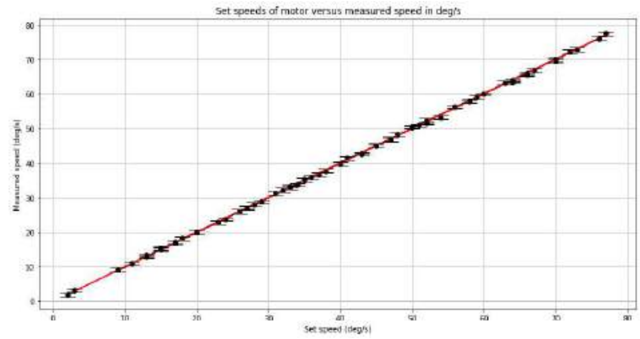

Fig.5. Set speed versus measured speed of single axis motorised testbed

Fig 5 shows the velocity control performance assessment of the testbed. The angular velocity set using the Odrive motor controller is compared with the actual measured angular velocity of the motor using the magnetic rotary encoder output. Each measured reading is the average of sixty readings taken over a period of sixty seconds. The assessment of the velocity control of the motor found a correlation between the two data sets using linear regression as 1.002 ± 0.003. A similar graph was constructed for the position control accuracy of the testbed which was found to be 1.018 ± 0.016. Both methods can be used to accurately control the velocity and position of the motorised testbed.

B. ADCS MB Testing

To date, basic acceptance testing has begun on the CS ADCS MB. This involves ensuring the ADCS MB can communicate with each sensor and actuator provided by CS. The output of each sensor using the ADCS MB is also being used to verify the functionality of each component of the ADCS. Tests have been performed to ensure that the mode and state of the ADCS MB can be changed and that the time and positional data of the ADCS MB can be modified. These two features are important as the WBC payload needs to be implemented in test mode as it allows for commanding of the magnetorquers, and for the positional and time data to be accessed and altered. Once these test procedures are complete, the ADCS MB will be mounted to the single axis testbed described and the performance of the sensors on the motherboard will be assessed. After EQM integration, the ADCS components in the full system will be evaluated using the single axis testbed.

VI. Conclusion

This paper has presented the design, construction and assessment of a single axis motorised testbed that can be used to analyze the performance of the sensors and actuators of the attitude control subsystem of 1U to 3U CubeSats. In the specific application to EIRSAT-1, the testbed has the capabilities of verifying the performance of the on-board gyroscope, magnetometers, sun sensors and magnetorquers. This testbed will be used for subsystem testing of the EQM and FM ADCS Motherboard of EIRSAT-1 and the EQM and FM of EIRSAT-1 [6]. This project will provide a basis for future designs for testing the attitude control subsystem of EIRSAT-1, and other missions such as the addition of other sensor or actuator capabilities, and the development of the 3-axis test rig.

Acknowledgment

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Flight testing of parachute recovery systems aboard REXUS

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The Supersonic Parachute Experiment Aboard REXUS or SPEAR mission is a mission by the Parachute Research Group (PRG) of Delft Aerospace Rocket Engineering (DARE). The primary objective is to test the in-house developed Hemisflo ribbon drogue parachute at supersonic conditions. To achieve this a test vehicle is placed in the nose cone of the REXUS sounding rocket and released near apogee (75-85 km). From apogee, the test vehicle shall follow a ballistic trajectory and deploy the drogue parachute above Mach 1.5.
Besides testing the drogue parachute at supersonic velocities, the secondary goal of the mission is to gather a full validation data set for the DARE ParSim and TumSim simulation tools.
The test vehicle is aerodynamically stabilized and centred around the drogue parachute deployment system. The parachute system is completed by two main parachutes for a safe landing. Data on the parachute performance is stored onboard. All mission critical data, including video, is sent down via telemetry.
The paper describes the SPEAR project, design and testing envelope. Furthermore, an outlook is provided on diverse experiment possibilities for parachute testing on the REXUS sounding rocket.

Keywords— Hemisflo ribbon parachute, drogue parachute, supersonic, SPEAR, REXUS, test flight.

I. INTRODUCTION

Within Delft Aerospace Rocket Engineering (DARE), the large envelope advanced parachute system (LEAPS) is used as the recovery systems of multiple flagship projects such as Aether, Stratos III and Stratos IV [1]. The Hemisflo ribbon parachute is chosen as the drogue parachute for this system due to its high supersonic capabilities as it can theoretically function up to Mach 3.

When looking at a parachutes deployment and flight, the two most critical parameters are the dynamic pressure and the velocity regimes encountered. The Parachute Research Group (PRG) is able to test the parachutes extensively with wind velocities up to 30 m/s and dynamic pressures up to 0.5 kPa in the Open Jet Facility (OJF) at the TU Delft. In these tests the drag and subsonic stability performance of the parachutes can be determined. These conditions however, are not comparable to the deployment conditions of the parachute in flight.

The team has designed a test vehicle, as part of the Parachute Investigation Project (PIP), to test parachutes at dynamic pressures up to 7 kPa. This is comparable to the main and drogue parachute deployment conditions in larger DARE missions.

It is however more difficult to test the supersonic capabilities of parachutes. Large size supersonic wind tunnels exist, but are very expensive [2]. Aside costs there is a difference in drag and stability behaviour between parachute performance in a wind tunnel (infinite mass scenario) or in flight (finite mass scenario) [3]. Therefore, a supersonic flight test would be preferred to validate the supersonic performance of this parachute.

Inspired by SuperMAX, flown on MAXUS-9 [2], PRG looked into a sounding rocket piggyback mission for testing the LEAPS drogue parachute. This led to the proposition of a new DARE mission that was to fly on the REXUS sounding rocket as part of the REXUS/BEXUS project; the Supersonic Parachute Experiment Aboard REXUS (SPEAR).

This paper gives an overview of the mission and the measurements to be performed. Furthermore, it gives an overview of the electronic and mechanical design of the experiment, and an outlook on future flight testing of parachutes.

II. MEASUREMENTS

As the SPEAR mission aims to flight test the Hemisflo parachute at supersonic conditions, it is essential to obtain sufficient data in order to reach a post-flight conclusion on the parachute performance.

The data set gathered will include force data from parachute inflation which will be used to validate the "small parachute, supersonic conditions" inflation models in ParSim. Three load cells are used to ensure the parachute inflation load can be measured, even when the parachute force does not act in line with the longitudinal axis of the test vehicle.

Next to this, the inflation behaviour and stability of the parachute will be observed with an HD, high speed camera which is mounted in an upward looking configuration towards the parachutes.

The final onboard sensor to study the drogue parachute is the inertial measurement unit (IMU). This sensor will measure the acceleration in three axes as well as rotational rates.

The inflation of the parachutes can be directly observed from the video images of the on-board camera. The loading conditions during parachute inflation and flight will be obtained during post processing of the load cells and IMU measurements.

Next to parachute related measurements, more data will be gathered from the SPEAR flight in order to validate other assumptions and simulation programs within DARE.

Because SPEAR is expected to experience aerothermal heating effects during re-entry, the heat fluxes will be

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measured to validate the thermal models currently implemented in ParSim. Finally, a camera is mounted on the REXUS rocket in order to confirm that the separation of the vehicle occurred without any issues and a pressure sensor is used for main parachute deployment.

III. Flight simulations

The SPEAR trajectory consists of four major flight phases, these can be seen in Figure 1. In the first phase, ascent, SPEAR is attached to REXUS. The test vehicle will be separated shortly before apogee.

After this SPEAR and the REXUS rocket will go their separate ways. From around 60km, SPEAR will undergo a re-entry phase. During this second phase, SPEAR is stabilized by a ballute stabilizer, which ensures the vehicle remains close to a zero-degree angle of attack. This is needed to increase the terminal velocity of the vehicle at drogue parachute inflation. Furthermore, as ParSim assumes a constant angle of attack [5], it is preferred to keep the vehicle as stable as possible.

After re-entry, the vehicle enters the third phases of its descent. In this phase the Hemisflo parachute will be deployed, at supersonic conditions over Mach 1.5. This will be at approximately 25km and is dependent on the conditions at the launch site, the performance of the REXUS rocket and the final parameters of the SPEAR vehicle. The team also performs a sensitivity analysis on the velocity at drogue deployment to ensure this requirement is met [4]. Figure 2 Shows the minimum deployment altitude as a function of the apogee altitude and vehicle mass of SPEAR.

When SPEAR reaches an altitude of about 1 km, the main parachutes are deployed to ensure it lands safely with a landing velocity lower than 10 m/s.

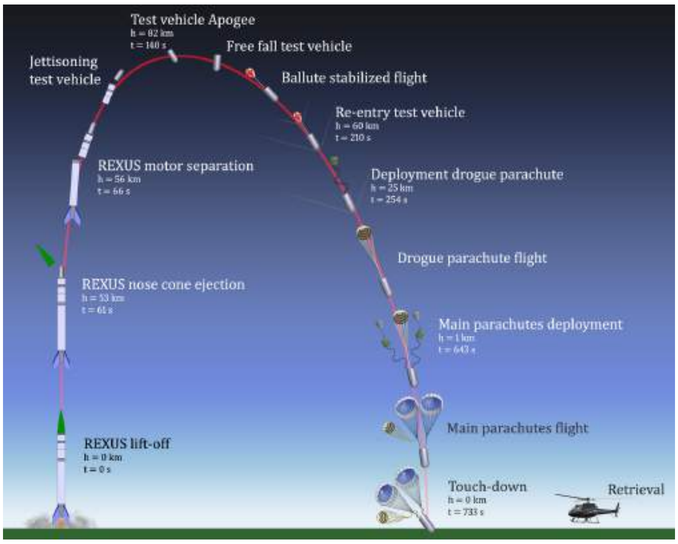

Figure 1 Flight Sequence of the SPEAR mission

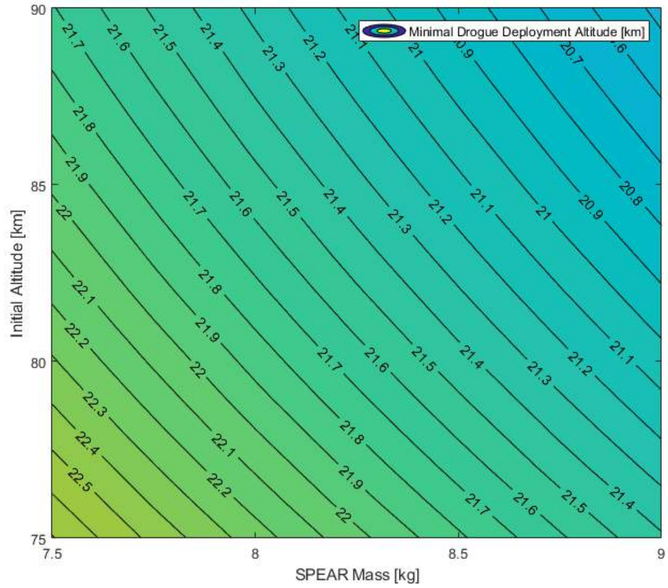

Figure 2 The cross-over point for SPEAR deployment at M=1.5

Other than the deployment, the expected forces from the parachute on the vehicle as well as the decelerations during the flight are essential for designing the test vehicle. The constraints lead to the flight envelope of the vehicle which can be seen in Figure 3. Here the maximum parachute inflation loads as well as the maximum dynamic pressure the parachute can handle are plotted in one figure. The envelope shows that the limiting factor in this mission is not the drogue parachute but the main parachutes. This can be seen as the main parachute inflation occurs on the edge of the flight envelope.

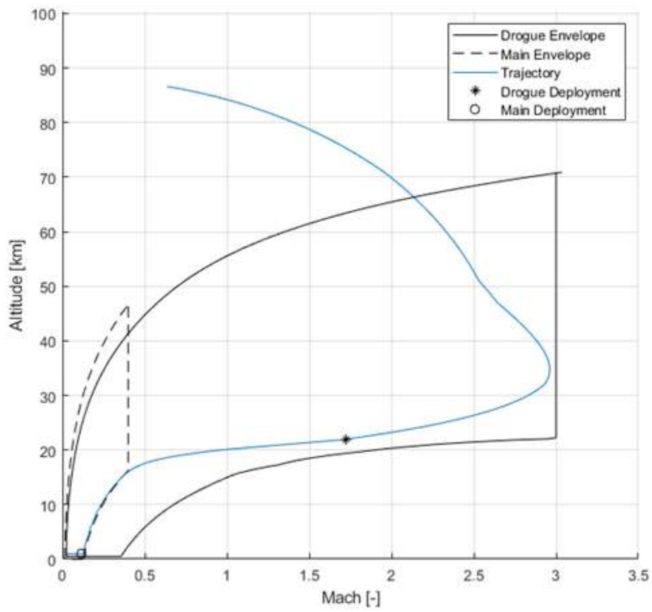

Figure 3 Flight Envelope of the SPEAR Flight

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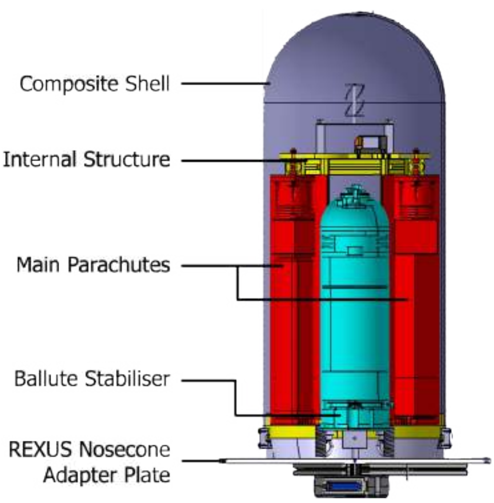

Figure 4 SPEAR vehicle – front view

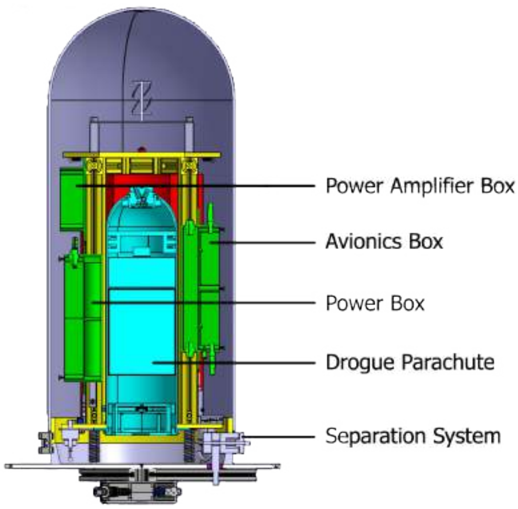

Figure 5 SPEAR vehicle – side view

IV. Mechanical design

The mechanical design of SPEAR includes the parachutes, deployment and separation systems. A mechanical overview can be seen in Figures 4 and 5. These are bound to a set of strict constraints, given that the vehicle will fly within the REXUS nose cone. The limited available volume and mass formed driving requirements for the design. The use of design tools such as CAD-software were of large value during the design process and greatly helped the team determine the feasibility of the design. Finding a suitable location for all subsystems without interfering with each other was arguably one of the most difficult challenges faced throughout the entire design. Because the parachutes and electronics already occupy a significant amount of the available volume, the team had to be creative and flexible to allocate all components to a suitable location, while keeping an eye on the feasibility of assembling the vehicle. Several design changes followed from the initial assembly procedures to facilitate integration. Using Dassault Systems CATIA v5 as a 3D design tool was a very convenient way to arrange and visualise all components inside the vehicle. Production methods such as 3D printing and wood laser cutting enabled the team to produce a low-cost mock up vehicle.

A. Vehicle shape

Throughout the conceptual design, it was found that a conical vehicle shape was unstable due to the centre of pressure being in front of the centre of mass. The SPEAR team investigated different stabilisation options including deployable grid fins, small wings, and a stabilisation parachute. The latter was chosen to stabilise the vehicle during its descent in the upper atmosphere. The parachute was sized such that it provides adequate stability whilst allowing the vehicle to reach supersonic conditions at drogue deployment. This led to a 19 cm diameter ballute parachute. Due to the small size, this Ballute is difficult to produce and test.

As the vehicle was now stabilised, the available volume could be increased by adjusting the shape of the shell from being conical to cylindrical with a dome.

B. Parachutes

A total of six parachutes are required for the mission, and thus have to fit inside the vehicle, which in its turn should not conflict with the internals of the REXUS nose cone. These six parachutes consist of the stabilizing ballute, one Hemisflo ribbon drogue parachute and two main parachutes with one pilot chute each. The drogue parachute is connected to the main structure via three load cells. The two main parachutes are used to decelerate the vehicle to a safe landing velocity. Disk-Gap-Band parachutes are chosen as main parachutes as these have proven to be very stable during wind tunnel tests. This type is used to land the Stratos nose cone as well, for which SPEAR can provide useful parachute flight data. The main parachutes are attached to the main internal structure at the bottom of the main parachute canisters.

The drogue parachute is deployed using a hot gas deployment device (HGDD). The system works by igniting 0.5 grams of nitrocellulose, generating a rapidly increasing amount of gas in a confined volume, generating a pressure of 36 bar. The gas pushes the parachute and the sabot, shearing off a set of nylon bolts that keep the system closed [6]. The HGDD is used for the drogue deployment since it can deploy a parachute with a high velocity of 25 m/s, decreasing the chance of entanglement between the drogue parachute and the test vehicle. One of the main challenges encountered during the HGDD design was to figure out a suitable amount of nitrocellulose. Not using an adequate amount of nitrocellulose will not shear off the set of nylon bolts and eject the parachute with a sufficient velocity, whereas using too much will generate too much pressure that cannot be taken by the canister, leading to structural failure.

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Furthermore, as the drogue parachute is deployed around 25km, the HGDD has to function in low ambient pressures and air density. Pyrotechnic actuation in low air density is difficult, which is why the entire pyrotechnic section is sealed. Despite the seal, ignition in near vacuum is being thoroughly tested for redundancy.
A simple spring system is used to deploy the main parachutes and stabiliser. This system works by compressing a spring and keeping it in place using a wire. The wires are cut using wire cutters which releases the springs, ejecting the parachutes out of the canisters [6].
Most of the mechanisms inside SPEAR are triggered using Cypress wire cutters. These are lighter solutions than servo-actuators and are very reliable as they are bought commercially off-the-shelf. Three sets of two wire cutters are used to trigger the deployment of the stabilisation parachute and both main parachutes. A set of two is used for redundancy reasons.

C. Separation system

The separation system holding SPEAR during the ascent which releases the vehicle on command was part of the design as well. As SPEAR has to cope with the qualification level vibrational loads up to 12g RMS, it requires a strong and stiff separation system [7]. The selection of this system was challenging as there was a large variety of design options and changing requirements which made it difficult to perform a trade-off. For all hold down and release mechanisms, springs were chosen as ejection system.

The simplest hold down and release system was determined to be one where the vehicle is bolted down on REXUS and the bolts are disintegrated upon actuation. This can for instance be done using explosive bolts, explosive nuts, or Frangibolts®. The main advantage of the latter system is that it can be reused and does not use pyrotechnics which increases testability and safety [8]. Unfortunately, these parts are expensive and procuring them was not possible for the SPEAR project. Another concept, used by the REXUS 25/26 BESPIN experiment [9], was considered as separation system as well. Here three tensioned steel cables hold down the experiment in the longitudinal axis supported by columns which prevent lateral movement. TRW Pyro cutters cut the steel cables and springs eject the experiment. For the SPEAR mission this design would need 3mm thick steel cables, which are not possible to cut with the TRW cutters. Aside this there were doubts on the repeatability of assembly, as the pretention in these cables is very difficult to determine.

The last design option, a clamp band, was selected, see Figure 6. This design originally did not score best in the trade-off, due to a relative high mass and production effort. As there is more experience within DARE with this system [10] and it has a high stiffness, vibration resistance and reliability there is a high confidence in its success. The system consists of two half bands, connected by an actuation and tensioning mechanism. The actuation is done by cutting an M3 bolt with a Cypres wire cutter®.

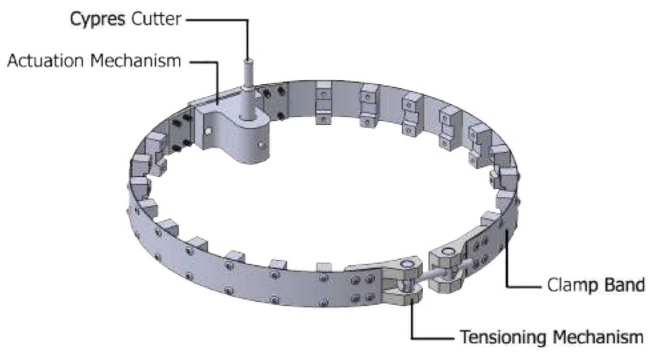

Figure 6 Separation mechanism – clamp band

V. ELECTRONICS DESIGN

The SPEAR electronics system contains three processing units and is responsible for actuation, recording flight and sensor data, handling video inputs, and telemetry. The three processing units are stored in two compartments in the SPEAR structure: the power subsystem container and the avionics subsystem container, see Figure 5.
The power subsystem container holds the lithium-ion batteries used to power the entire electronics system as well as the battery management system (BMS) processor. This processor controls the battery charging process, distributes and monitors the power throughout the electronics system and measures the environmental conditions inside the power subsystem container.
The avionics subsystem container houses two processors: the supervisor (SUP) processor and the Raspberry Pi Compute Model 3 (RPI) processor. The SUP processor controls actuation of pyrotechnical devices and handles the interface between SPEAR and the REXUS Service Module. The SUP processor also handles data storage in on-board black boxes as well as the retrieval subsystem, which includes a GPS module, Iridium modem and a VHF beacon for locating purposes.
The RPI processor is used for video processing and handling the high data-rate telemetry downlink. This downlink is achieved through an on-board software defined radio along with a power amplifier. Aside from telemetry handling the RPI processor also handles and stores the sensor data of the sensors used in SPEAR, including a heat flux sensor and load cells.
The use of a high data-rate telemetry downlink allows for live digital video streaming and uncompressed live data output, effectively providing the SPEAR team with data during flight through a telemetry receiver in the SPEAR electronics ground station setup. Part of this data can be used to monitor and predict the trajectory of the free-falling unit(FFU) in case the retrieval subsystem fails to provide the location of touchdown. Aside from retrieval purposes this direct data stream is captured directly by the ground station and can be used for post processing purposes. It therefore provides the SPEAR team with a great deal of data in case of unsuccessful retrieval of the vehicle.

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The data provided by the SPEAR electronics system will be essential for validating calculations on parachute, structural and thermal design.

VI. Outlook

Within the REXUS program, multiple experiments have been performed in the re-entry research area [11]. However, SPEAR is the first mission aiming to flight test a parachute recovery system. It could be considered to continue parachute research with new student missions that participate in the REXUS/BEXUS program. As can be seen in the SPEAR envelope, supersonic velocities can be obtained with a test vehicle. Testing a larger ballute stabiliser or the Disk-Gap-Band main parachutes supersonically are interesting subjects for future missions. These test vehicles should accommodate for the new requirements of these missions.

In the beginning of the SPEAR project, the location of the experiment within the REXUS rocket was still unsure, and multiple options were considered. These different configurations could be considered for future parachute research in the REXUS program.

The REXUS rocket offers three payload bays: two modules and one spot within the ejectable nose cone, see Figure 7.

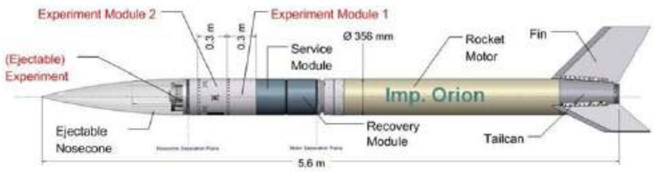

Figure 7 The REXUS Sounding Rocket [7]

An FFU can be deployed from all these locations. The module however has restrictions on the maximum size of a cut-out in the structure to maintain structural integrity, which limits the maximum size of an FFU [7]. This could be considered a feasible option when the experiment and vehicle are scaled down in complexity and size significantly. It would be recommended to only include one parachute, the test article, in this case. As the weight distribution of this FFU can lie more towards the dome end of the vehicle, it can be designed as such that it is inherently stable during descent.

Another possibility is to integrate the experiment in the REXUS nose cone. This has been done in some REXUS experiments such as Aquasonic [12]. This implementation removes the design of a main outer structure and separation system from the team's workload as the REXUS nose cone and nose cone ejection system are used for this. It also increases the area and volume that one can work with immensely. It does however require intense collaboration with REXUS as there are much more interfaces with the rocket compared with using the nose cone adapter plate as the single physical interface.

Lastly, one could opt to apply for the unconventional option of recovering the REXUS engine section. An experiment module could be placed between the yoyo de-spin and REXUS recovery module. This does have the downside of a large entanglement risk with the fins, and that the orientation of the engine under the parachute has to be switched. This is alike the Aether mission by DARE, and radial deployment should be considered [6].

Conclusion

The SPEAR mission provides the Parachute Research Group with a vehicle capable of fulfilling the need of supersonic parachute testing. The combination of IMU, load cells and cameras can provide a full overview of the supersonic capabilities of the LEAPS Hemisflo drogue parachute. The addition of a heat flux sensor to the sensor suite also allows for verification of the in-house developed simulation tools ParSim and TumSim. Based on first simulations, the vehicle is capable of reaching the velocity conditions required. However, further sensitivity analysis will be performed to ensure mission success.

Finally, it can be concluded that supersonic parachute testing is possible on board the REXUS sounding rocket and within student capabilities and experience.

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Fly a Rocket! Undergraduate rocket science

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***Abstract*— The Fly a Rocket! programme is an intensive training course in rocket design and construction aimed at undergraduate students. The open-ended assignments, as well as the hands-on campaign, were the perfect lab-test for an engineering project. Activities like this prepare students for the problems faced in professional life, in commercial or research careers, and provide an active transfer between universities and institutions like ESA or sector companies.**

***Keywords*— active transfer; Andøya Space Center; education; ESA Education; NAROM**

I. Introduction

The Fly a Rocket! (FaR!) programme is a hands-on training and learning opportunity for undergraduate students pursuing science and engineering degrees.

The programme consists of a pre-study course followed by a rocket campaign at the Andøya Space Center (ASC). One of the authors (Alondra Solá) participated in the second cycle of the FaR! programme, where 23 students with 14 different nationalities gathered to prepare and launch a rocket into the Arctic airspace. It was both an intensive training course in rocket design and construction and a summer camp for space enthusiasts. The immersive, comprehensive experience made a strong impact on her: academically, personally, and professionally.

This paper will give a summary of the FaR! programme and the personal experience of a participant at the campaign. In addition, as members of the academic community (undergraduate student and professor), we the authors present our views of this programme.

The programme is organized by the ESA Education Office, the Norwegian Center for Space Related Education (NAROM) and the Norwegian Space Agency. The campaign took place at the Andøya Space Center, 310 km north of the Arctic Circle.

Fig. 1. The Fly a Rocket! 2018-2019 participants at the Andøya Space Center. Source: ESA [1]

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FaR! was aimed at undergraduate students in the first two years of their undergraduate education. Applications were open to students from all ESA member states, as well as Canada and Slovenia.

The 23 participants came from space-related backgrounds such as Aerospace Engineering or Space Sciences, as well as other degrees with intrinsic applications such as Physics, Biology, or Natural Sciences. Each participant brought their cultural and technical background to the table, and through this fascinating exchange a competent team was formed.

II. Pre-study and assigments

The pre-study course was designed to make sure all the students had a mastery of the fundamentals of rocket science, so that they could take full advantage of their time at ASC. It also helped the organizers of the programme to estimate the students' technical level, as well as their familiarity with the theory and the software they would need during the campaign.

NAROM prepared extensive pre-study material, available online, about rocket engines, aerodynamics, satellites, and orbital dynamics. The contents also introduced the particular rocket that would be launched (the Mongoose 98) and explained preliminary simulations of its flight.

In addition to this study material, the students were asked to complete two assignments. The problems were varied and required both meticulous study of the subject matter and research on other rockets and past missions. The scope was much broader than what university assignments are usually limited to, and creativity was a must. In many cases the participants were not asked to provide "the right answer" but rather the argument that best supported the conclusions presented.

For example, one problem was to create a simulation of the student rocket's flight. Several approaches could be taken to simplify this problem. Mass could be assumed constant (as initial weight, average weight, or dry weight), or the motion could be assumed to take place in a two-dimensional plane. The calculation of aerodynamic force meant taking into account not only varying velocity (which, in turn, implied a set of differential equations) but also varying air density; the best method to find this was left to each student to determine.

In a question on orbital mechanics, the solution could be found numerically, via Gibbs' method, or geometrically via the application of Kepler's third law. In optical analysis, the student was to use images from the Sentinel satellites, taking into account vegetation, climate, cloud cover, etc. when selecting an area of study. This left a lot of room for exploration and encouraged imagination, rather than the simple application of the theory.

The staff at NAROM returned the assignments with detailed feedback, allowing each student to detect the weak spots of their work, and leaving open space for re-analysing conclusions. Thanks to these references, the students were able to improve their reporting, scheduling, and problem-solving skills, as well as the overall quality of their work.

During the pre-study course, the participants were in contact via an online social media group. This allowed them to get to know each other and gave the group a sense of community before the campaign even began. It also allowed each student to share their expertise, especially coming from different STEM areas. Many participants worked to help each other understand the assignments and troubleshoot problems. It also provided an easy way for them to stay in contact after the campaign, which had led to close collaboration among them.

III. Campaign!

The week-long rocket campaign at ASC was the apogee of the FaR! programme; there were lectures, lab work, team-building activities, excursions, and rocket launches.

The lectures complemented the pre-study material but also branched out to cover a wide variety of topics. Experts gave lectures on rockets, signal processing, the history of the ASC, balloon science, the space industry, the origin of the universe, and much more.

The goal of the campaign was to experience the process behind a rocket launch. The students assembled the payload, soldered sensors, simulated trajectories, built and launched two weather balloons. They took control of the NAROM launch procedure and ran through the checklist. The telemetry stations were manned by students, and others filled all the usual rocket range roles: Range Control, Principal Investigator, Payload Manager, Pad Supervisor, etc. After a few delays the rocket (named "Ballistic Rocket Experiment Inside the Troposphere") was launched successfully.

The rocket was prepared by four student teams, each with their own particular assignments and deadlines: Sensor Experiments, Telemetry and Data Readout, GPS and Simulations, and Payload.

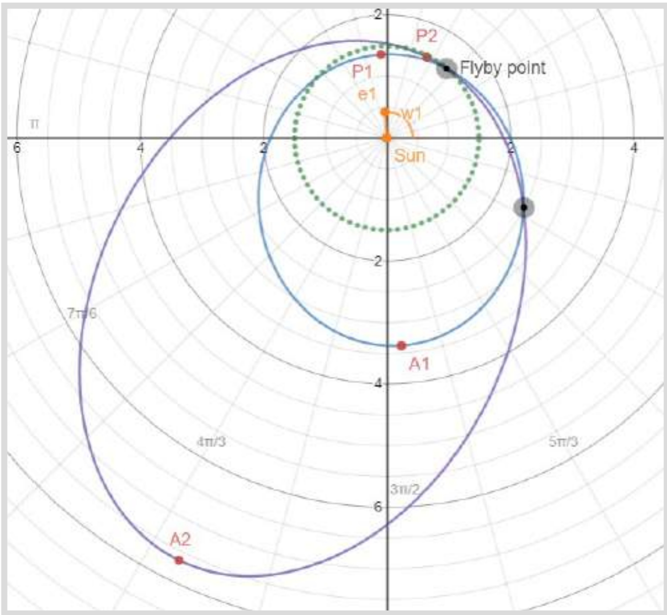

Fig. 2. Graph of the Rosetta spacecraft's orbits during 2009 Earth flyby, pre-study assignment, FaR! 2018-2019.

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The three members of the Payload team were responsible for the disassembly of the rocket, mounting of the sensors and transmitter, reassembly, and testing. Each sensor and plate, after being assembled, was tested and mounted on the payload. The technical details were well explained, and the NAROM staff were always available. However, in many cases there were no fixed instructions, no right answer. The location of each sensor, the design of the balloons, the useful parameters for sensor measurement: all these were the students' prerogative, and they in turn took responsibility for each of those decisions.

After the launch, the students spent the last day of the campaign doing intensive analysis of the information obtained from the rocket by the telemetry stations. There was no outline for this work, nor was there a required result. They were encouraged to select the data they wanted to analyse and pursue their own lines of research, following their own curiosity and interests. In the same spirit as in the pre-study assignments, the students did not have detailed instructions or expected results. Instead, they were asked to argument the results that their study provided.

Being free to select what they wanted to analyse allowed the participants to delve deeper into a particular topic and tackle all the challenges that came with each decision. Within that freedom, however, the analysis required the proper application of physics, maths, and research methods; this was often not visible at first glance. It also forced the students to make critical decisions and focus their efforts. With over 4 million data points to process, strategy was key.

Each group selected the data sets they wished to study and got to work: they organized and cleaned the data, interpolated, looked for correlations or contradictions, or compared the data to past missions and simulations. They reached plausible conclusions, or else reanalysed their method. The groups also shared their results and scripts, working together to get the most out of the limited time. The results of this analysis were processed and presented by each group of students at the end of the campaign and discussed with the experts from NAROM.

Fig. 3. Auroras at night over ASC. Source: Giovanni Bezze.

IV. Educational aspects and active transfer

The Fly a Rocket! programme offered students a chance to experience a rocket launch first-hand. It was a memorable experience, but its importance goes beyond the cool factor.

As we have introduced in this short communication, FaR! made a deeper impact. Students learned the ins and outs of a launch campaign and gained technical expertise. They were also forced outside the protective blanket of their universities and given tasks without a unique correct answer. Through this approach, the students can catch a glimpse of how work is carried out in the aerospace industry.

The programme's importance, however, goes beyond informing them about their future; it teaches them how to become useful and proactive agents of that industry. It teaches them to become the kind of professionals that will spearhead innovation in a healthy and responsible way: learning to work as a team in spite of differences in background, meeting deadlines, building communication and leaving room for friendships to flourish. The space industry needs to become more innovative and self-aware; we the authors believe this human factor is vital in forging that future.

Specifically for aerospace students, we believe that the planning, manufacturing and launching a of rocket is an irreplaceable experience. While every university should aspire to provide this for their aerospace students, that is not always possible in smaller departments. Moreover, for students aiming to enter the space sector, this particular experience grants expertise that both space agencies and students will benefit from.

FaR! taught an important lesson: designing, calculating, integrating, and manufacturing a rocket is an engineering challenge that requires a team, working together. In addition, breaking down the construction of a rocket payload and assigning teams for its development is, we believe, an excellent analogy for any design or construction process in engineering.

Tasks must be detailed and allocated, which brings out the different profiles and areas of knowledge of the industry. As a result, the team members are forced to develop their own skills and affinities within the subject they are working on.

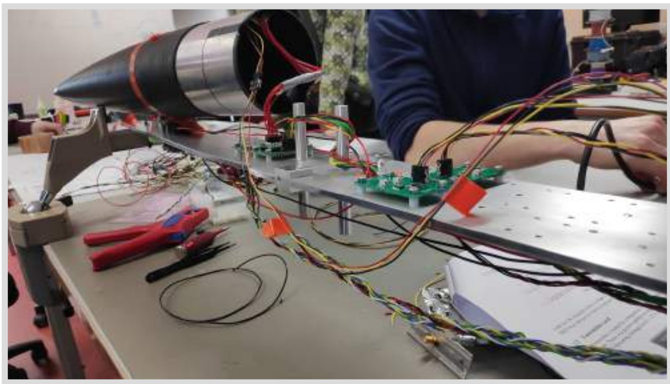

Fig. 4. Nosecone and payload assembly, NAROM lab at ASC.

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This approach is often lost in the university, as courses tend to provide a fair and uniform education to everyone, and graduates tend to find difficulties defining their niche. The lack of individualization has proven to be a common factor in the Spanish education system; graduates struggle when looking at job offers because the specific profiles from the industry don't match with what they feel they have learned at university.

Consequently, FaR! and similar programmes (like the Student Aerospace Challenge or the exploding Hackaton competitions) help to build students' confidence and allow them to overcome these limitations.

From the point of view of a growing department of a big university like ours, we believe that these kinds of international events are crucial. They teach students to participate and take on an active role, showing them the world outside their usual frontiers--both physically and professionally. There is a transfer of work methodology and knowledge between colleagues. They benefit others as well; the participating students brings the example of direct experience back to their classmates. This helps them expand their creativity and overcome their fears when applying, studying, and building their own projects.

A department in aerospace engineering must be in constant movement, learning and improving--especially if it aims to become a landmark in the European academic sector. This whole "movement" starts with the students and continues with the professors. When mentoring students to apply to European competitions and activities, the academic staff is forced to look away from their research for a moment. It puts the focus on the students and their projects. This helps them to keep in touch with the student body, and in some situations, to see an unexpected application of their research.

Finally, we believe the highlight of the programme was the creative aspect. It has been shown that open-ended assignments force students to break through the limitations their classical education has built around them, and to creatively explore all the possible solutions. These programmes teach them to find interconnections between different branches of their knowledge, to detect and understand their mistakes and to listen to others' proposals; these skills are desirable, not only in a good scientist or engineer, but in any person.

Fig. 5. The Pad Supervisor in the ASC bunkerhouse moments before launch. Source: ESA [1]

Unfortunately, bachelor's degrees are often designed with little margin for these activities. Even if professors aim to develop new approaches, the increasing number of students per faculty member and the decreasing funding of public education [2] force the evaluation process to be highly restrictive. Students are usually fed information and asked to retain it until the exam. Even with assignments or projects, a lack of time or personal resources often hinders the creative process.

V. Conclusion

Fly a Rocket! was a comprehensive campaign in rocket technology that provides an active transfer between university education and the aerospace industry.

The pre-study course highlighted the importance of critical thinking in a very organic way. Students found that it challenged their grasp of the theory in a way formulaic university assignments cannot, and demanded creative problem-solving.

The campaign was technically rigorous. It required attention to detail and ultimately gave undergraduate students access to a ballistic rocket, with all the responsibility that comes with it. It also was an intensive teambuilding experience, as it required collaboration with the other participants--strangers from different cultures and backgrounds worked closely together during long days on a demanding project.

The FaR! programme and others like it are a key component in the education of future engineers and scientists. They fill the gap between theory and practice, exams and rocket launches, academia and professional life. In the rapidly-evolving space sector, it is crucial that we educate engineers and scientists that can face a completely new problem and ask themselves not just “How do we find the answer?” but first, “What exactly is the problem? What kind of answer do we want, and why? And in this pursuit, what should we take into account?” Repetition leaves no room for innovation.

Acknowledgment

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Combination of Interdisciplinary Training in Space Technology with Project-Related Work through the CubeSat SOURCE

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Abstract— **In April 2018, student work on the first satellite mission primarily dedicated to education at the IRS, SOURCE (Stuttgart Operated University Research CubeSat for Evaluation and Education) began. The phase A study resulted in a three-unit CubeSat design and a cooperation with a variety of industrial partners. Besides its educational purpose, the mission features technological and scientific objectives, the latter of which concentrate on the field of re-entry research. With the current status of the project, a large number of students have been introduced to and trained in all aspects of a satellite mission, like management, project sequences, concurrent engineering, space industry standards, and the application of specialized technical knowledge. This paper gives an overview of the CubeSat SOURCE and its educational approaches.**

Keywords—CubeSat; re-entry; student development

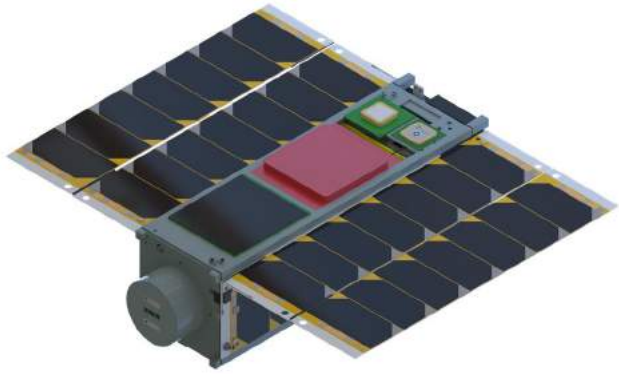

Figure 1: The current structure of SOURCE

I. Introduction

The everyday life of an aerospace student usually consists of theoretical lectures, supplemented by a few practical modules. However, these modules have a maximum duration of one semester and represent only a small phase of a project. Therefore, the need for a way of extending this theoretical knowledge with actual practical task arose and the SOURCE mission was started. This mission is a cooperation between the Small Satellite Student Society KSat e.V. and the Institute for space systems (IRS) at the University of Stuttgart for building a 3U+ CubeSat. In addition to those, multiple industry partners provide scientific payloads and technology demonstrators to fly on-board of SOURCE.

Within the project, the main work is done by students ranging from under graded bachelor students to almost finished master students. They are separated into eight different self-organized working groups. Each group is supervised by at least one PhD student of the IRS. This paper shall provide an overview of the student work within the SOURCE project. The current state of the structure can be seen in figure 1.

II. Mission Overview

The main objective of the SOURCE mission is the education of students from different fields of study in conceiving, designing, building, and operating a satellite system. This objective is supplemented by different objectives regarding the mission itself, separated into primary, secondary, and additional objectives. The primary objectives consist of the development of a reproducible CubeSat-platform and the verification of new technology for Space 4.0, provided by industry partners. The technology demonstrations comprise new types of solar cells by STI and AzureSpace, SmartHeaters by Airbus, automotive electronics for space applications by Fraunhofer IPA, and a 3D-printed sandwich structure with integrated electrical circuits by DLR.

The secondary objective is to investigate natural and man-made re-entry objects to understand the challenges of and gather data for a sustainable utilization of space. Observation of meteors during their burn out in the atmosphere and in-situ measurements during the re-entry of SOURCE itself shall provide data which can be used for the validation of meteor propagation and numerical re-entry simulations. It moreover points out the necessity of the ESA clean space initiative to the next generation of space engineers and scientists.

The additional objectives include the verification of another type of solar cells, the utilization of a star tracker build from a COTS camera and Earth observation in the visible spectrum of light.

SOURCE is planned to be launched to a 400 – 500 km Sun Synchronous Orbit or deployed from the International Space Station. The mission itself can be divided into two phases.

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The first phase starts after the deployment and commissioning of the satellite and lasts until 200 km, shortly before the re-entry. During this time, SOURCE will be used for meteor and Earth observation and investigates the performance of the automotive electronics and solar cells. Especially the degradation of the parts over time is one of the analysed key factors. This also includes radiation measurements and voltage monitoring. Additionally, atomic and molecular oxygen is measured during the decent to monitor the atmospheric density and composition. The communication is done via S-Band and uses the ground station of the IRS.

The second phase takes place between 200 km and the communication loss of SOURCE. During these last approximate 14 hours, the technology demonstrators are turned off and the behaviour of the satellite is monitored with the re-entry sensors. They consist of pressure and heat flux sensors as well as photodiodes for the tumbling rate and plasma analysis. The Oxygen sensors are used to correlate the behaviour with the atmospheric composition. To avoid data loss and the need for a ground station, the Iridium network is used as a secondary communications system additionally to the S-Band.

A. *Time Schedule*

The time schedule of SOURCE is tightly coupled to the semester cycle at the University of Stuttgart. This is due to the accompanied lecture and the participating students. Therefore, reviews are hold in multiples of half years. The first two reviews, the preliminary requirements review, and the preliminary design review are already passed. A critical design review is planned for beginning of 2020 followed by the flight readiness review (FRR) and the operation readiness review (ORR) roughly half a year later mid-2020. A possible launch is then intended after the FRR and ORR for the end of 2021. An overview of the time schedule is given in figure 2.

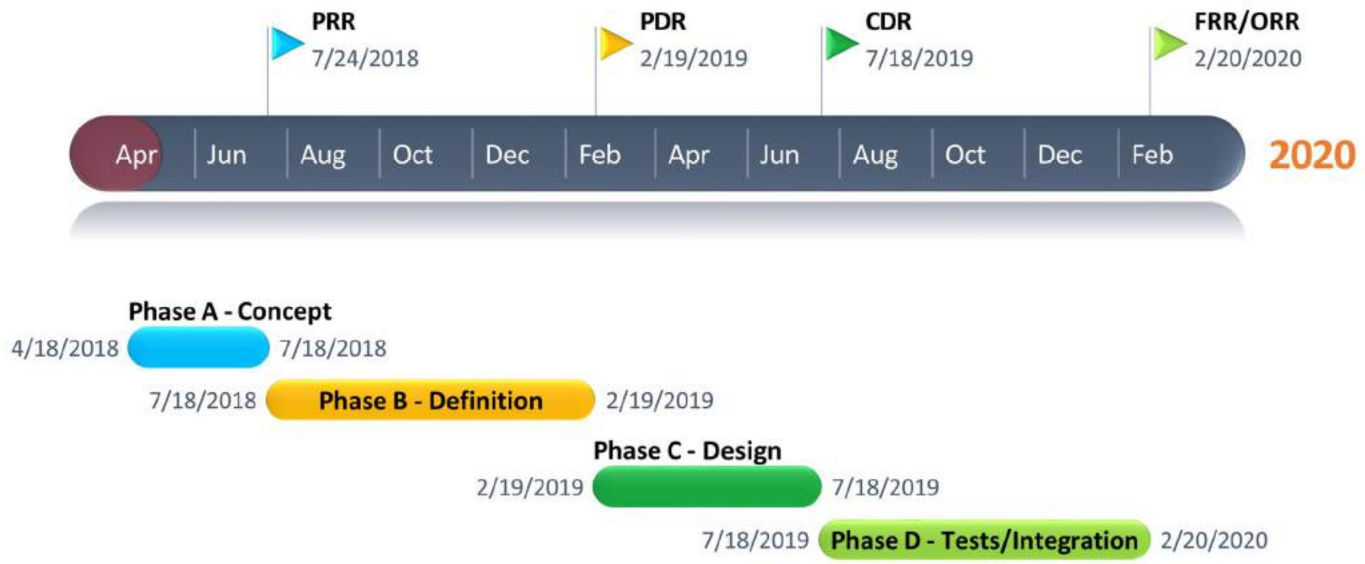

Figure 2: Time schedule of the SOURCE project

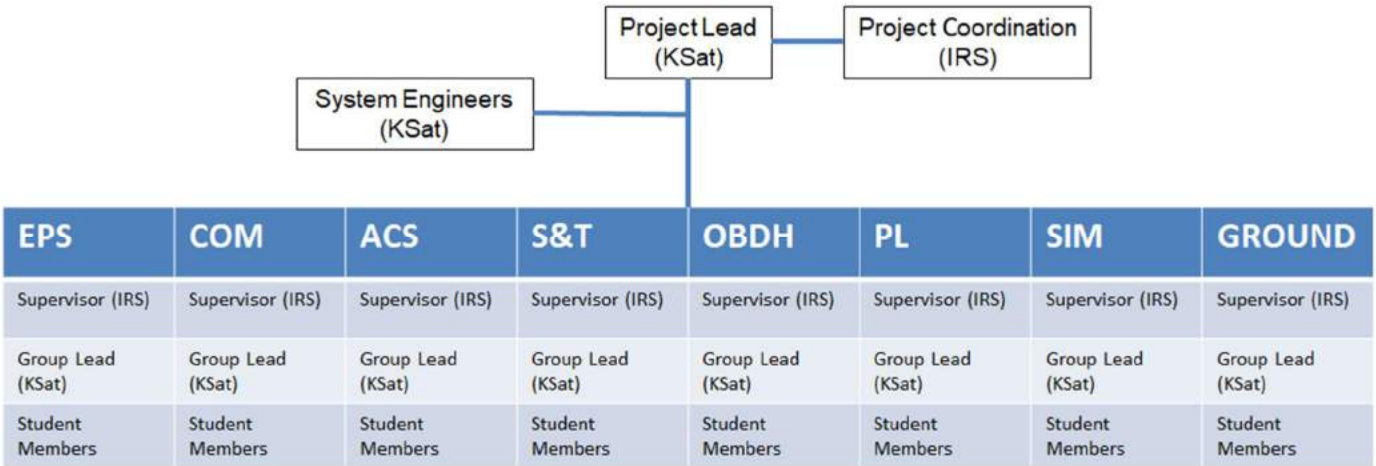

Figure 3: Organizational structure of the SOURCE team

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III. Student Involvement

The SOURCE project takes a new way in student involvement for space-related education at the University of Stuttgart. The main principle of this approach is that the students are in full charge of the complete project. Hence, they can participate in a space engineering and science project with no restraints. PhD students, staff members of the institute, and the endorsing Professor provide guidance and help to avoid critical issues during the development and operation of the satellite.

Moreover, the project is carried out by a tailored application of ECSS or PUS communication standards and by using industrial development, test and operation tools. Each project phase is accompanied by at least one review with national and international industrial and academic experts who assure the overall quality of the project work. For each review, a presentation and documentation is made for the complete project.

A. Organisation

The project is led by two student project leaders, which ensures a reliable management with high availability. Both are supported and supervised by a PhD student and a full-time employee of the institute. Every critical decision concerning the project is discussed in this group, which meets once a week and is in constant exchange. The student system engineers are part of this weekly meeting to get a current overview of the project phase and give feedback about the budgets and system interfaces. The decisions and issues are later discussed with the subsystem group leaders in a weekly meeting, which is also used for subsystem group feedback and work package status. There are eight subsystem groups in total, consisting of Power (EPS), Communication (COM), Attitude Control System (ACS), Structure and Thermal Control (S&T), On-Board Data Handling (OBDH), Payload (PL), Simulation (SIM) and Ground Control and Operation (GROUND). Every subsystem group consists of at least three student members and one student group leader. The group leader is responsible for the work package creation and distribution in OpenProject as well as the organization of the subsystem group meeting. This meeting takes place every week and is used to discusses subsystem group tasks and evaluate current issues. In each subsystem group, at least one PhD student attends these meetings as a supervisor. A structure of the hierarchy is shown in figure 3. To ensure that every project member gets an overview of the current project status, a general meeting is held every two weeks. The main communication of the project is done via Mattermost, an open-source, self-hostable online chat service, in which private channel messages can be distributed.

Besides the voluntary participation, the project is offered to students of all technical and scientific fields in the form of a course, which includes lectures and practical work. Beyond science and engineering students of the University of Stuttgart, the SOURCE project seeks to involve students of the further course of studies. An example of this is a recently achieved cooperation with the Hochschule der Medien Stuttgart, in which bachelor students of the study program Advertising and Marketing Communication elaborate a public outreach concept for the SOURCE project in the scope of a practical course.

B. Documentation

The whole SOURCE project is carefully documented, including all made decisions with their respective histories and trade-offs. The documentation is split into multiple individual documents for better clearness. This includes the main documentation, separated into nine documents, one overview and eight subsystems, the requirements documentation, all risk analyses, all test protocols, and additional management documents like a product tree, the work breakdown structure, and documentation tree. All documents are organised through this documentation tree. Within this, each document is classified to a subcategory and the respective number coming from the work breakdown structure. These subcategories include all subsystems and additional categories like tests, quality assurance and management. Within these subcategories, each document is assigned with a unique number and title resulting in easy classifiability just by the name of the document.

All documents are written using LaTeX. One the one hand, this forces students to make themselves familiar with a new environment and on the other hand LaTeX simplifies the collaboration within a team of over 50 members. In addition to this, LaTeX can be versioned and synchronized using the GIT-software[1]. With this software, it is possible to revert to an earlier state of the documentation when a change damages a document. Since all documents are synchronised with a server, regular backups of the whole documentation are guaranteed.

This extensive documentation helps with the changing members of the SOURCE team so no knowledge is lost, and new members can easily look up the current state and it also provides good training in precise writing of technical documents already during the study.

IV. Challenges

The aim to source all technical and a large share of the organisational workforce from students brings certain challenges with it. Whereas on the one hand, it can be difficult to recruit the right cast for the more time-demanding leading positions, enticing committed students to neglect their study progress over the project can be a problem on the other hand. To weight the time expenditure the project demands from its participants with fast progress has been one of the major concerns so far. Another difficulty turned out to be posted on the project by balancing the technical staffing of the team. It was observed that participating students tend to choose those working groups whose contents coincide with theoretical knowledge acquired during their studies. This leads to a chronic lack of interested participants in certain important subject areas, such as high-frequency technology. This problem reveals gaps in theoretical lecture plans of aerospace engineering students as the main participating party. In these fields, the outreach to

[1] https://git-scm.com/

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students who are willing to familiarise themselves with the subject matter is much more demanding than in fields covered by bachelor modules. Related to this issue, bringing new participants to a level on which they independently can collaborate and learn on the project becomes more difficult as the complexity of the satellite system grows. The task to get new interests acquainted with their unfinished object of work is assigned to the group leads, adding a demand for didactic skills to the already high requirements of this position. Thirdly, internal project communication should be mentioned here, as the growing number of both current and former participants poses a risk of information loss and diverging work statuses. The SOURCE project meets this problem by giving leading positions to those students who can reassure to accompany the project for the longest. This way, students holding those positions gain a long-term overview of their subsystem and can check design decisions for consistency. However, they can only supplement extensive documentation of every step the project takes.

V. Progress And Achievements

A. Educational

Currently, the SOURCE team consists of 45 students where roughly 1/3 participates in the offered lecture. Overall, SOURCE supervised around 100 students so far. Of the 15 to 20 participants in the lecture every semester, around 1/3 again stays in the project after their final presentation and grading. This combined with only fewer leaving people from the project results in a slowly growing number of participants. Some students currently holding leading positions within the projects started during the lecture. The overall development of student members over the different phases can be seen in figure 4. Overall, the SOURCE team comprises many different courses of study. This includes a big portion of aerospace students, but also students from electrical engineering, computer science, renewable energies, and simulation technology. This contributes to having experts for all different challenges occurring during the project phases.

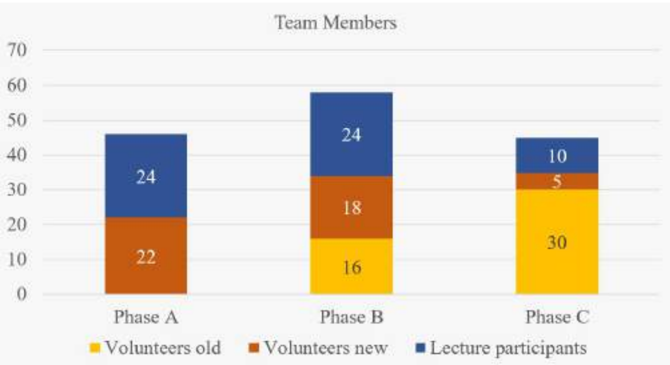

Figure 4: Team members over the different project phases

In addition to the participation in the lecture, SOURCE also offers final theses. Within these, the students are supervised by one of the PhD students, already working on SOURCE. So far, parts of the communication testbed, the sensor qualification, the solar panel arrangement and holding mechanisms, and the trade-off for the secondary communication system were conducted throughout bachelor and master theses. In the case of the solar panels, this also included a cooperation with one industry partner, where the student was able to develop his thesis on the partner's premise.

To guarantee for a constantly good and growing quality of the lecture, regular surveys are conducted with the students. This feedback is then integrated into the next round of the lecture.

B. Mission

After the PRR was held in July 2018 and passed in October of the same year, SOURCE passed the PDR by the end of August 2019. However, work on the system entered the detailed design phase four months before the official PDR pass.

VI. Outlook

Over the next phases, more and more specialised experts are needed for the final integration, implementation, and operation of the project. This combined with the will to spread space knowledge and projects to other courses of study, it is planned to integrate the project with a couple of supporting lectures for satellite development into the curriculum for computer science at the University of Stuttgart for both bachelor and master students. As for the further development, testing, and launch of the satellite, an intermediate CDR is planned to take place at around half the time to the final CDR. Just like with full reviews, a review board will be invited to read the documentation and join a presentation of the project. Afterwards, they are asked to provide any critical points and challenges, which must be tackled until the final CDR. With the results from this intermediate CDR, it is planned to hand in an application to ESA's Fly Your Satellite program. This program assists students in developing and testing their satellite by providing access to experts and testing facilities. Finally, this program also provides launch opportunities to successfully integrated and tested satellites.

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Evaluation of Preliminary Design Review (PDR) formats in student space projects.

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In any engineering project, the Preliminary Design Review (PDR) is a major milestone. The design is presented to non-project members who provide feedback. This feedback is used by the team to incorporate in the detailed design. The review can be done using written documentation and/or an oral presentation.

Student space projects often have a tight timeline which imposes constraints on the PDR process. Depending on this timeline and the availability of team members and reviewers, the PDR can be done in several ways. Variations can be made in: level of detail in documentation beforehand, the time between sending documentation and PDR, the format of the feedback and the implementation of the feedback.

The article originates from the widely varying PDR formats the authors experienced in different student space projects. Within Delft Aerospace Rocket Engineering (DARE) a PDR was held on both the Stratos III and Stratos IV student-built sounding rockets. Furthermore, a PDR on the Supersonic Parachute Experiment Aboard REXUS (SPEAR) mission was held both within DARE internally and within the REXUS/BEXUS program.

In the article, the pros and cons of the various formats are discussed together with their applications. As cases, the REXUS/BEXUS and DARE PDR formats are compared to each other and the ESCC standard.

Keywords— Preliminary Design Review, PDR, student project, DARE, REXUS, ECSS.

I. Introduction

During the Supersonic Parachute Experiment Aboard REXUS (SPEAR) project, the team experienced a different format of the Preliminary design review (PDR) in the REXUS/BEXUS program than it was used to within DARE. The different setups also resulted in different feedback. This led the team to wonder if these formats can be altered and combined in a way to tailor to a student project's needs. This paper explains key aspects of both reviews and evaluates some of their pros and cons.

The process of a review in space projects is also streamlined by the ECSS guidelines. The paper will provide a short summary of the process presented in ECSS and what the advantages of this method can be for student space projects.

II. DARE

DARE is a student rocketry society with approximately 150 members. These members work in multiple teams and projects. R&D teams have around 10-15 members whilst flagship projects like Stratos have around 60 members, distributed over different technical and non-technical sub teams.
The design cycles in DARE consist of a conceptual, preliminary and detailed design. The conceptual design phase is mostly only reviewed within the team itself, where during the PDR all members of DARE and, on occasion, external reviewers from the Technical University of Delft or companies are invited.
The design is shown during a presentation in which the design trade-offs and choices are explained. After each section, a question and discussion round is started in which the reviewers can question and explore the design. The reviewers' experience with similar (sub-)systems leads to recommendations for the design which is one of the key points during this review process.

Main characteristics of a DARE PDR are:

- No or limited documentation is sent beforehand.
- If documentation is sent, this is only done shortly before the PDR (one to two days).
- Low number of external reviewers is present.
- The presentation on the design and design choices is relatively long and can last up to two hours for a subsystem.
- The feedback from the reviewers is not structured in categories.
- There is little to no time for the reviewers to let the design sink in and generate questions or comments.
- There is much freedom to dive into different discussions and reviewers can bring up new ideas or solutions to the problems of the team. There is room to discuss this elaborately.
- Reviewers usually have many questions on the design after the presentation, as it does not fully cover all the details.
- The level of detail of the design in a PDR is not pre-determined, thus varies often. Sometimes the design is still more in the conceptual design phase.

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The DARE PDR’s as they were, were long and somewhat ineffective. As the reviewers did not have proper documentation or time to read the provided documentation, questions were often not relevant or very broad. This led to the presenter spending the majority of the PDR time on explaining the mission and the conceptual design and less time on the design issues. This was made worse by the observation that many members had different opinions on what the preliminary design needed to contain.

Based upon the REXUS selection workshop and the REXUS PDR, a first improvement to the DARE PDRs were made. Changes included:

- Documentation is sent out at least one week beforehand.
- The PDR starts with an overview of the mission.
- The PDR contains a 30-minute presentation on the final preliminary design broken up in clear subsystems.
- Discussions and questions are done per subsystem.
- More in-depth content discussion than usual DARE reviews were possible.
- Reviewers can give written feedback on documentation if they aren’t able to come to the PDR.

The modification of the DARE PDR format led to a better structure and noticeably better results for both the SPEAR internal PDR.

III. REXUS

Within the REXUS/BEXUS program Cycle 12, the SPEAR team had its PDR in February 2019. Within the REXUS program, the student team hands in an updated version of their Student Experiment Documentation (SED) two weeks before the review. The SED contains the full preliminary design and progress up to that point. The PDR is held with the student team and a panel from the REXUS/BEXUS program containing multiple members of the different organising parties and different specialties. During the PDR, the student team gives a short presentation of 20 minutes to summarise the design and any design changes that were made between the SED and the PDR. After this, the panel gives their feedback on the design and the documentation in an hour during which the team makes notes. This means the review is relatively one-sided, in the presentation from the team towards the panel and vice versa for the feedback. Minutes of the feedback, including feedback on the SED, is sent to the team a few weeks after the design review.
In the same week as the PDR, a Q&A session with all student teams of that cycle and the REXUS panel is organised. Here issues with the design or controversial points can be discussed in more detail where also alternative solutions can be introduced.

Main characteristics of the REXUS PDR:

- The documentation (SED) is provided two weeks prior to the review.
- High paced student project means content can actually change significantly in those two weeks.
- PDR itself is somewhat one-sided.
- Review and comments are more in-depth as elaborate documentation is read and studied beforehand.
- Q&A session with the panel allows for more in-depth discussions and is a much-needed supplement to the PDR.
- Elaborate minutes, including action points, are sent after the review, enabling the team to ensure the feedback was interpreted correctly.
- The content of the feedback on the written documentation is different compared to DARE’s. It goes into the design much deeper and also focuses on details, not solely on the basic working principle. Aside this it also includes feedback on the quality of documentation itself.

IV. ECSS

The European Cooperation for Space Standardization created an extensive set of guidelines meant to improve consistency and facilitate design efforts within the European space sector. The published standards on design reviews are discussed in the following section, which is based on ECSS-M-ST-10-01C ‘Organization and conduct of reviews’ [1].

The overall purpose of a review is to examine or evaluate the current status of the project in which the problems faced throughout the design process are discussed. Reviews often act as a moment of reflection.
The ECSS identifies three different steps during the review process:

- ‘Review initiation’
- ‘Review data package preparation and distribution’ allows the review participants, REXUS, to familiarize with the to be reviewed documents.
- ‘Review of the documentation’ includes a kick-off presentation during which RID-forms (Review Item Discrepancy) are used. The issues, remarks and questions from the RID-forms are afterwards addressed during meetings between both parties. The review team, SPEAR, is then expected to compile all results and conclusions that arose from the review.
- ‘Review findings and conclusion’ covers the examination whether the objectives of the review were met.

ECSS-M-ST-10-01C includes a list of requirements that serve as guidelines to a productive review for both the review team and review participants. The general requirements serve mainly to make sure that constructive feedback is exchanged and that any issues are correctly addressed.

The four following roles should be filled during a review:

- The review authority approves the review procedures, examines review reports, makes the recommendations

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and decides whether or not the review objectives have been met.

- The customer ensures that the review can be held by providing the necessary means, such as a data management system for the review data.
- The supplier's role is to provide all logistics, documentation, data and RIDs for the review.
- The review team leader mainly manages the review teams' activities and approves the RIDs.
- The review team reviews the documents and subsequently provides feedback using the RID-forms.

The chronological order of a review should be as following:

- A prerequisite key point serves as a check that the review can start.
- The kick-off meeting introduced the to be reviewed documents and product
- During the coordination meeting, the documents are reviewed, and all RID-forms are released.
- In a collocation meeting, the RIDs are discussed, following with action points that should be undertaken.
- After the review team close-out meeting, the results from the previous meeting should be summarized
- Finally, the review authority meeting confirms the outcome of the review and creates a review authority report.

The final steps of a review include the follow-up of action points and processing of the feedback received through the RID-forms.

V. Comparison of PDR formats

When comparing the three PDR styles; Old DARE, New DARE, and REXUS, one can see that where the Old DARE style allowed for too much discussion, the REXUS format however does not allow for interaction during the PDR. The latter is solved by the introduction of a Q&A session during the REXUS training week. This however, is not feasible in most student projects as there are often insufficient external specialists.

For most student space projects, it is unfeasible to follow the cycle proposed by ECSS as this takes place in a much longer time span. A much larger part of the ECSS process takes place on paper, with meetings to coordinate the process. In a student project it is still recommended that the one PDR moment stays central in the review process. However, some advantages are identified, of which the RID-forms is the most significant one, allowing for structured written feedback.

Both the REXUS and the ECSS formats include documentation to be sent out before the PDR. However, in the REXUS PDR format this means that the team should not change the design or documentation for this period. Given the short time span of a student space project, two weeks is quite long in a high paced student project. The use of RID-forms creates a compromise where the documentation is sent out 2 weeks before the PDR, but the team can still updates the design in this period.

VI. Recommendations

For student space projects, the team proposes the following set up that is efficient and thorough but still allows for implementation into student projects.

- T-3w – Reviewers are identified and asked. Important is to ensure a broad scope and experience of the review board.
- T-2w – Documentation is sent to reviewers
- T-1w – Final call for RID forms
- T-0 – Presented PDR
- T+1w – Send out minutes of PDR
- T+2w – Final feedback on minutes
- R+3w – PDR phase finished

The PDR itself should be set up such that the following topics are discussed:

- Overview of mission and concepts to ensure all reviewers are on the same page
- Overview of the RID forms that are not solved or addressed with explanation
- Preliminary design overview of the system and subsystems
- Preliminary design of the system interfaces
- Overview of risks
- Overview of budget
- Question round organised per topic

Even though this set up requires a total of six weeks, it provides the team with two feedback moments. As the first one is written, it allows for the team to tackle these before the presented PDR. When the points mentioned above are followed the presented PDR gives a complete and total overview of the project. By adding an introduction talk on the mission and the conceptual design, the team can ensure the review board is on the same page and that a more efficient PDR can be held. The inclusion of the RID-forms allows the team to start addressing issues in the two weeks prior to the presented PDR. This removes the downside identified in the REXUS PDR style.

By sending the minutes to the reviewers, the team can ensure that the written down feedback is as the review board intended it.

Most importantly, the Preliminary Design Review should be planned as a review phase, not a review moment. This setup also allows for a good processing of the received feedback instead of having to directly continue with the next design phase.

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CONCLUSIONS

Student teams should never underestimate the usefulness of design reviews during their space project if done well. This is maybe even more important for the PDR than for any other review. Given the three different styles of design reviews, the team proposes a combination of the ECSS and the REXUS review. This allows for more discussion during the PDR, alike the DARE model.

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Building a Low-Cost Soyuz Simulator to Teach Orbital Navigation

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***Abstract*—Space flight presents many dynamics unseen in any other domain. As such, they can be often hard to teach, and to have students develop an intuition for, even at a university level. A great benefit of cost efficient low-fidelity simulators is that they can enable users to directly interact with complex situations such as those encountered during space missions, whilst keeping a low learning curve for the user thanks to abstraction or simplification of the situation in question. Simulators can enable their users to start developing an intuitive understanding of complex topics such as orbital rendezvous, spacecraft docking, re-entry and navigation by instruments after only a few hours.**

This paper presents the design and build process, as well as the use cases of a low-fidelity simulator for the Soyuz TMA spacecraft built at the International Space University for educational purposes. The simulator is designed to provide a simplified and cost-efficient rendition of the on-board instruments and controls in a Soyuz TMA spacecraft descent capsule using commercially available components and allow students to manually perform in-orbit maneuvers that astronauts might perform over the course of a real mission. The paper focuses on design challenges associated with developing a user-friendly simulator without losing important aspects of how the Soyuz is controlled and behaves, discussing design decisions and trade-offs performed. The exact hardware and software architecture used in the final version of the simulator is also detailed.

Keywords—simulator; Soyuz; education

I. Introduction

Since the very first humans started training to launch into space, spacecraft simulators have been used to prepare astronauts for missions. By creating a simulacrum of a spacecraft on the ground, in a controlled environment, a powerful training tool can be created within which both nominal and dangerous scenarios can be simulated [1]. The trainees can then intuitively learn the proper actions to take in diverse situations while staying in a safe environment, rehearsing all aspects of spacecraft operation [2]. For such applications the simulators are made to be "high-fidelity", replicating accurately the parts of the spacecraft being simulated, and require the user to already hold deep knowledge of the systems being simulated.

While high-fidelity simulators are irreplaceable tools for real space training, simpler "low-fidelity" simulators that only broadly simulate real spacecraft can also be used to teach or study some aspects of spaceflight without requiring extensive training on the part of the users. The Institute of Space Systems (IRS) at the University of Stuttgart has demonstrated this with their low-fidelity Soyuz simulator, which is used in their aerospace-engineering course, and has been used in studies about the effects of prolonged missions on spacecraft piloting skills [3] [4].

This paper presents a cheap and relatively portable simulator design (total mass under 30 kg), built using about 550€ of components that can simulate any stage of a Soyuz mission, and provide a student or research subject with similar manual and automatic control options that the pilot would have, using a low-fidelity control interface inspired by the Soyuz TMA. An in-depth report on the simulator, including all information necessary to recreate it, can be found in [5].

II. Design Choices

When considering different design possibilities, the main driving factors were low learning curve, low parts cost and the immersion factor of the simulator. "Learning curve" is defined as the difficulty that a user with only basic knowledge of the Soyuz's operating principles will experience when using the simulator for the first time. How intuitive the user will find the simulator controls and interface strongly influenced the design. "Immersion" refers to how much (from the user's perspective) their experience felt similar to piloting a real spacecraft. It is an important factor in keeping the user engaged with the simulator, and increases the simulator's effect on the user's interest in spacecraft physics and engineering.

The simulator's design process was driven by the afore-mentioned factors, and heavily inspired by the IDS panel of Soyuz TMA and the Soyuz simulator at IRS in Stuttgart, with significant simplifications.

A. Software Design Choices

The software core of the simulator is built using the Orbiter 2010 Space Flight Simulator, developed by Martin Schweiger of UCL [6]. Orbiter presents a highly versatile framework for simulating, rendering and controlling the movements of spacecraft within a simulated solar system under the influence of realistic Newtonian Physics. While these features are crucial for the development of a simulator, what makes Orbiter particularly suited for use in a simulator setup is its highly modular software stack and the way it allows the user to interact with spacecraft instruments.

"Modules" within Orbiter allow for the creation of add-ons controlling the behaviour of different software components such

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as spacecraft, planets, instruments, etc. (cf. Fig. 2) and "plugins" are fully separate from Orbiter's core software and files, allowing for entirely new functionality unanticipated by the original developer to be seamlessly integrated into the software without conflicting with other such modifications. These features allow the community to develop countless add-ons that all work well together, making Orbiter perfect for an easy-to-build simulator.

The simulator designed uses the Soyuz v.1.0 add-on that implements the Soyuz TMA and certain internal systems with high accuracy, such as the Kurs docking radar, functional solar arrays and batteries and individual manoeuvring thrusters [7]. A highly-detailed ISS model is provided by the ISS v3.2 add-on [8]. These add-ons were used based on the design suggestions given in [9].

The other important feature of Orbiter is the "MFD" or "Multi-Functional Display" approach for simulating onboard spacecraft instruments. The user can open different instruments in windows called "MFDs" and interact with each instrument via a set of up to 12 mouse-clickable buttons. Orbiter comes with a variety of instruments built-in that can be used to help with atmospheric flight, orbital rendezvous planning, executing accurate orbital plane changes, docking, etc. Instruments can also control spacecraft systems, allowing for high-level user-controlled behaviour like pre-programmed manoeuvres or even full autopilot behaviour, making them very similar to the IDS in the Soyuz spacecraft.

Each Instrument has 6 input buttons on the left and right side, with 1 to 3 characters used to describe their functionality. The functions of the buttons vary dynamically with the instrument's state, depending on the instrument selected. The bottom 3 buttons are used for switching instruments, displaying options and turning the instrument panel on/off.

Orbiter also allows easy set-up of custom simulation scenarios. Any specific time (past or future) may be defined, and any number of spacecrafts placed in specific orbits or at particular places on a planet's surface.

B. Hardware Choices

In order to provide the user with a visual control layout somewhat similar to that found in the Soyuz TMA IDS, it was decided from the start that the final design will include one central main display showing the view from the Soyuz periscope, and two separate screens displaying Orbiter's MFDs. Ideally, input controls for the MFDs would be intuitive, and not require the use of the mouse.

Different methods, including physical buttons, mouse and touch screens were considered. Touch screens were picked as an easy-to use solution that is both more intuitive for the user as compared to mouse controls, and requires little assembly compared to physical buttons or switches (15 buttons per instrument panel would be required). The touch screens each display a single MFD window and can be interacted with by touching different control buttons shown on the displays. Testing with first time users has shown immediate understanding in how to manipulate the instrument panels.

Each display has a resolution of 1024 x 600 pixels, with the LCD units measuring about 160 x 92 mm. The displays have a different aspect ratio (the ratio between width and height of the display or window) to Orbiter's MFDs resulting in unused space around the left and right ends of each screen. This is due to the

Figure 1: Soyuz Simulator main screen, instrument panels and controls.

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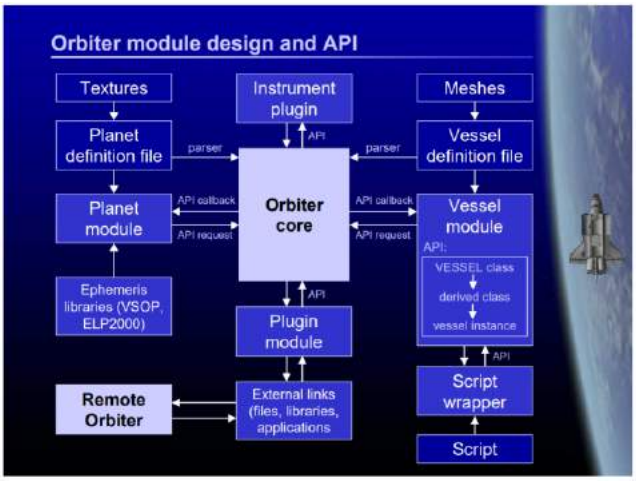

Figure 2: Orbiter Software Architecture [6].

rarity of ready-to-use touch displays with aspect ratios other than 16:9, while Orbiter's MFDs are closer to a 4:3 aspect ratio.

The displays were mounted on a large sheet of plywood that was then affixed to a monitor stand. The monitors connect via HDMI for the video signal, with a separate micro-USB cable needed for touch input and power. This brings the number of connected monitors to 3, requiring the use of 2 ASUS EAH5450 GPUs, as each GPU supports only up to 2 simultaneous video outputs.

By default, all MFDs in Orbiter are rendered in the same window as the rest of the program. Orbiter 2010 comes packaged in with the "ExternalMFD" addon, which when enabled allowing for additional MFDs to be rendered in separate windows. In this design, the ExternalMFD add-on is used to place 2 MFDs on the touch displays. The MFDs are identical in all functionality to those in the main Orbiter window, with all Instruments add-ons automatically supported.

The ExternalMFD windows require to be opened manually during each session, which would be highly inconvenient. This was automated by using AutoHotkey, a scripting framework for controlling mouse movement, key presses and certain application behaviour in Windows [10]. AutoHotkey provides a complete scripting language, allowing complex pre-programmed and input-based mouse behaviour, and is often used to automatically open and configure graphical applications. In this design, an AutoHotkey script was used to automatically launch Orbiter, open two ExternalMFD windows via scripted key presses and window resizing operations, then drag each window to the appropriate position on the touch displays.

Figure 3: The "Docking" MFD helps keep track of the docking target and align for approach.

To replicate the Soyuz manual thruster controls, a pair of 3-axis analogue USB flight sticks are used. A Thrustmaster T.Flight Stick X and a Saitek Cyborg 3d Rumble Force were used in this case. The sticks are designed for use with flight simulator computer games, with each stick providing 4 analogue (or continuous) input axes, and a number of push buttons. Each stick can be rotated along 2 axes (X and Y) and twisted along the Z axis; the 4th analogue input is provided by a continuous slider on the Thrustmaster stick, and by a rotating axle on the Saitek stick [11] [12].

The 3 axes of each stick are mapped to the manoeuvring thruster groups similarly to the control sticks in the Soyuz spacecraft, with the Thrustmaster placed to the right of the user allowing for attitude control and the Saitek placed to the left allowing for translational control. Control of the main engine is mapped to the slider on the right stick.

While Orbiter is developed with analogue stick input as a possibility, the default version can only accept input from a single device. To add support for multiple analogue devices, the Fly By Wire addon was used [13]. The add-on provides a way to significantly reconfigure all flight stick inputs that are passed to Orbiter, as well as support for multiple analogue input devices.

III. Final Version

The final version of the simulator can let students run through a Soyuz mission from launch to landing or start at the beginning of any major ISS mission stage, such as orbital rendezvous, docking, deorbit and re-entry. The control layout is meant for a single student to use. A short manual was produced for familiarizing ISU students with the simulator controls and principles of spaceflight in Orbiter.

TABLE I. SOFTWARE USED

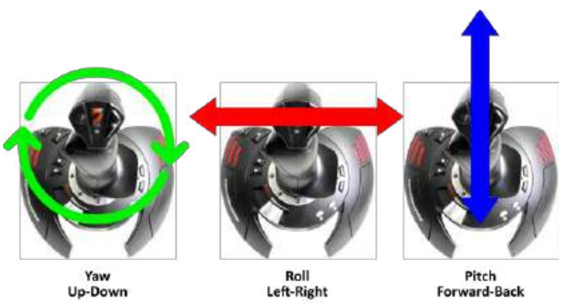

Figure 4: Flight stick control axes, with uses for the right stick (attitude control) then left stick (movement control) respectively.

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Software	Usage
Windows 10 Pro, 64 bit	Operating System
AMD Catalyst	Graphics Drivers installation to use 2 GPUs
Orbiter 2010	Simulator Framework
JoyToKey	Flight Stick input mapping to mouse and keyboard
AutoHotkey	Automate opening of ExternalMFD windows

TABLE II. SOFTWARE PACKAGES FOR ORBITER

Package	Features
Orbiter 2010	Orbiter Core
Soyuz v1.0	- Soyuz TMA Spacecraft - Soyuz Launcher - Fregat Upper Stage - Soyuz mission scenarios at different stages in mission - Can use OrbiterSound if installed
ISS v.3.2	- ISS - Soyuz TMA Spacecraft (less detailed model, overridden by Soyuz v1.0 add-on) - Progress M1 - Historic Soyuz mission scenarios
FlyByWire	- Multiple Flight Stick support and configuration - Deadzone settings and input axis mapping
External MFD	- additional MFDs can be created in separate windows

TABLE III. FULL COMPUTER HARDWARE CONFIGURATION

Component	Model	Amount	Socket/Connection Type	Rough Price in 2019 (eur)
Processor	Intel Core i5-3470	1	FCLGA1155	80
GPU	ASUS EAH5450	2	PCI Express	50
RAM	DDR3 Memory	8 GB	DDR3 DIMM	30
Motherboard and other PC components	N/A	1	N/A	100
Main Monitor	Generic 1080p LCD	1	DVI	90
Touch Screens	Generic 1024 x 600 LCD	2	HDMI (video) Micro-USB (touch input and power)	120
Flight Sticks	- Thrustmaster T.Flight Stick X - Saitek Cyborg 3d Rumble Force	2	USB	60
Keyboard and Mouse		1	2 x USB	15

IV. EDUCATIONAL VALUE

A few trial runs of the simulator were conducted with the help of ISU students that have not interacted with a spaceflight simulator before. Students were given the task of docking the Soyuz to the ISS from a starting position a few hundred metres away. This involved locating a vacant docking port, aligning the Soyuz for approach, approaching the docking port from the correct direction, and docking. An instructor was present to explain how to operate the simulator, give hints on good docking practices and answer the student's questions. First time students took 20 to 50 minutes to complete a full docking.

A video of one of these test runs can be found at:

https://youtu.be/xeEW5ZFLJh8

All students on the ISU MSS course have attended a few lectures on the basics of spaceflight mechanics about 6 months prior to when the simulator was tested. While no formal assessment of the simulator's effects on students' understanding of spaceflight mechanics took place, after docking the simulated Soyuz, students have reported feeling immersed while using the simulator, and that their understanding of spacecraft physics has improved.

V. CONCLUSIONS

In this paper, the design, capabilities and educational use cases of a low-fidelity Soyuz simulator built at ISU were presented. The simulator is capable of recreating all stages of a typical Soyuz TMA mission. It can be used by students to experiment with orbital mechanics by attempting to rendezvous with the ISS, learn to manoeuvre precisely in micro-gravity, perform docking and control a spacecraft during re-entry. Each of these operations is performed with instruments and controls not too different from those used in the real Soyuz but with a very low learning curve, providing students with an immersive atmosphere that allows them to develop an intuitive understanding of the underlying physics and engineering concepts in spaceflight.

The Orbiter Software's simple controls and standardised MFD instruments help make the simulator approachable for students with only a basic theoretical understanding of the concepts involved. For example, after a few lectures on the basics of orbital mechanics and orbital manoeuvres, a student can try their hand at performing the manoeuvres they learnt about with the simulator, hands-on. Orbiter's scenario system allows for instructors to quickly load pre-made scenarios for each student, while AutoHotkey speeds up the loading of MFDs.

Due to Orbiter's versatility as a spacecraft simulator, and its large user community, a number of improvements can be easily added to the simulator to expand its capabilities both as a teaching tool and for outreach, without additional hardware costs by using community-built add-ons with the presented simulator design. As it is currently set-up, the simulator can be made to simulate spacecraft other than the Soyuz, most notably it can be used to simulate near-future space missions to deep space, helping students understand the distances and manoeuvres needed for interplanetary transfers. Mods that add different hardware support can also be used to extend the simulator with additional hardware to fit more specialised use cases.

https://doi.org/10.29311/2020.48

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FLOMESS - Flight Load Measurement System for Sounding Rockets

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***Abstract*—The future use of rockets is increasingly shifting from national to private interest. Here, primarily economic aspects decide the further development within the rocket technology. Our experiment deals with the weight reduction of the rocket structure itself in order to optimize the ratio of payload to total mass of a rocket. Here the FLOMESS project want to continue a started venture at the Bundeswehr University Munich. The FLOMESS experiment is intended to measure the structural strains during the launch of a sounding rocket. The occurring structural loads will be calculated from the measured strains. Furthermore, the system shall measure the effects of thermal strain to isolate them from the measurement. This is necessary to determine the pure structural strains. Therefore, a redundancy system of strain and temperature gauges is used on the inner surface of the experiment module. This system of relating the measured strain gauge response to the loading is taken over from previous projects on the fundament of the Skopinski method. This method was adapted for our experiment and illustrates an application of the Skopinski method to sounding rockets, where modifications being made to account all types of loadings. An accurate knowledge of the loads during the flight shall help to improve the existing semi-empirical methods for calculating these loads in different flight positions of a rocket. Since these predictions influence the design of the rocket vehicle, efficient design is achieved by reducing semi-empirical safety margins and increasing overall payload mass ratios. FLOMESS participated in the REXUS/BEXUS campaign of DLR and SNSA and, as a test of the system, the experiment was launched on the RX25 rocket on 11 March 2019. The results will be used to further develop the measurement methods.**

Keywords*— *flight loads, flight loads measurement, structural strain, sounding rockets, Skopinski method, REXUS, RX25, failure analysis

I. INTRODUCTION (*HEADING 1*)

The idea to measure flight loads of a rocket was taken up by the Mobile Rocket Base (MORABA) part of the German Aerospace Center (DLR). After the predevelopment of a measurement module, a student team was founded in cooperation with the Institute for Lightweight Structures at the Bundeswehr University Munich (UniBw), to improve this module within the Rocket Experiments for University Students (REXUS) program. This paper deals with the development of a Flight Load Measurement System (FLOMESS) based on the theoretical foundations. In addition, it deals with the special requirements of a REXUS project and the calibration phase. Since a failure of the FLOMESS module occurred during the rocket flight, the results are presented in the form of a failure analysis.

II. THEORETICAL FOUNDATIONS

The Skopinski method [1] is used to calculate the resulting sectional loads at the position of the experiment module. The method assumes that a linear structural behaviour is existent. This allows, after previous calibration, the conversion of measured strains into the flight loads. This calibration procedure includes the application of defined load cases while simultaneously measuring the respective gradient of each strain output signal of the corresponding strain gauge bridge. To convert the measured strains of any number of strain gauge bridges into the required sectional loads, the calibration matrix β must be calculated in (1). A calibration matrix can be determined from the variety of several calibration tests with different sectional loads and load cases. If as many sectional reactions are applied as there are strain gauge bridges, a determined system with a unique solution exists. The character of the Skopinski method also allows a higher number of measurement locations to be included than sectional loads, which leads to an overdetermined system. In this case, the calibration matrix can be calculated using the least squares method. This represents the general linear case of the least squares method, whereby a numerical solution of the calibration matrix can be obtained using a minimization problem. After calculating the calibration matrix, the individual strain gauge output signals are weighted by the coefficients to the corresponding load. As a result of this, combined sectional loads can be calibrated.

$$L_j = [\beta_{ij}]\{\mu_i(T) - \theta_i(T)\} \tag{1}$$

Decisive for this are the number of strain gauge bridges, their orientation and their application to the inner wall of the experiment module. In order to characterize different loads individually, it is necessary to be able to produce a specific sensitivity via the orientation. Therefore, the eight strain gauge rosettes in the experiment module are applied in 0°/90° and ±45° arrangement and produce different output signals specific to the applied sectional load. The sectional loads during flight will then be a result from the multiplication of the calibration

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matrix and the strain output signals. In order to compensate any temperature influences, the strains will be subtracted in the post-flight phase by a determined correction function.

III. Development of a Flight Load Measurement System

A. Hardware

The FLOMESS experiment consists of the FLOMESS module ring with strain gauges. In order to compensate the influence of temperature, additional temperature sensors are installed. Fig. 1 shows the module ring as it was designed by Dohmjahn. It can be divided into three main hardware components:

1) Module ring with strain gauges and temperature sensors,

2) Amplifiers DMS-8 and PT-100,

3) and E-Box with MFC-2 and FLOMESS Interface Board

Strain gauges and temperature sensors

A total of four measuring points are arranged on the inside of the module ring. In order to calculate the flight loads, four measuring points with two differently arranged strain sensors each are installed. The temperature sensors are mounted in such a way that they are close enough to the strain gauges to accurately measure the surrounding temperature but still have enough distance not to influence the measurements. The RXSM of the RX-25 rocket is located directly above the FLOMESS module. This configuration leads to a small distance between the high-frequency antenna of the RXSM and the electrical wiring of the strain gauges [3]. To minimize the interference, two changes are carried out. Firstly, all unshielded wirings are shortened to reduce the antenna surface. Secondly, ferrite beads are applied to the unshielded wirings between the PCBs and amplifiers. To improve mechanical stability of the shielded wirings, four ferrite beads are gathered to a bundle and fixed to the inner wall of the module with an epoxy resin adhesive as shown in Fig. 2. Organizing all four cables of each strain gauge rosette also increases clearness of the wiring arrangement.

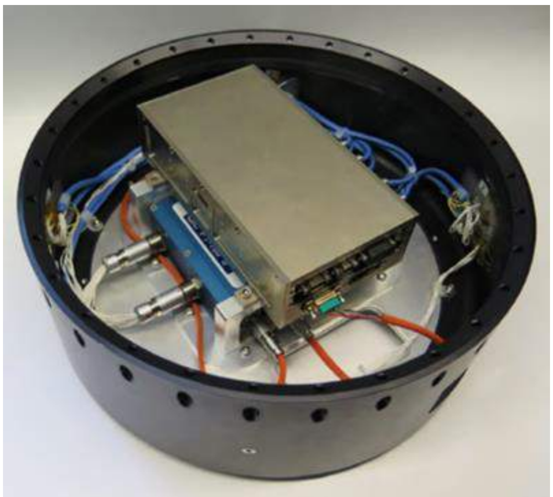

Fig. 1. FLOMESS module ring

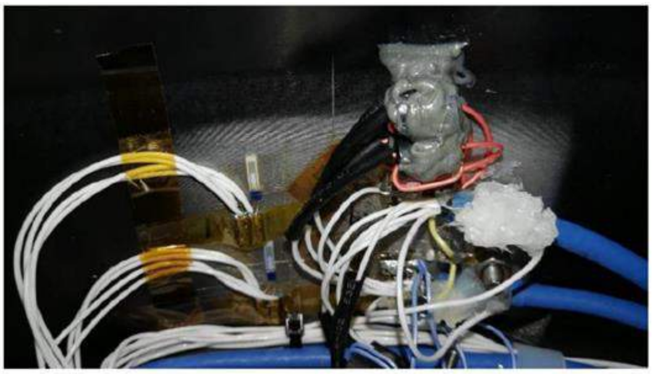

Fig. 2. Configuration of sensors with Ferrite Beads

DMS-8 and PT-100 amplifiers

The DMS-8 module is used as the amplifier module for the strains. The PT-100 module is used to measure the temperature. Both are measurement modules originally used in automobile production. The analog signal is amplified and converted into a digital signal in an A/D converter.

E-Box with MFC-2 and FLOMESS Interface Board

For mounting in the FLOMESS ring and for protection against physical influences and radio waves the MFC-2 and the FLOMESS Interface Board are located in an E-Box. The main task of the MFC-2 is the signal processing. The MFC-2 supports various interfaces, of which the CAN bus and RS-422 connector were used due to compatibility with the amplifiers and the REXUS Service Module (RXSM). The MFC-2 is connected to RXSM via the FLOMESS Interface Board. The 28 V power voltage of the RXSM is fed to a TRACO 4 Power step-down converter with an output voltage of 5 V with a maximum current of 2000 mA. A common mode filter is connected to the power supply generating a ripple free power voltage. Optocouplers are used for the galvanic isolation of the rocket signals. Voltage Peaks over 28V have no influence on the connected hardware. Returning voltage peaks from the FLOMESS electrical components are blocked because of the galvanic isolation.

B. Software

The software is divided into two sections, the onboard software on the FLOMESS module ring and the Ground Control Station (GCS).

Onboard Software

The onboard software is part of the measurement system in the data processing function. In addition, the software is processing the rocket signals including the timeline. At least, it is responsible for the up- and downlink. To program the MFC-2 the programming language C++ is used together with the RODOS real-time operating system, including modifications and tools kindly provided by MORABA. The core of the software was already finished by MORABA as part of the master thesis of Karl Domjahn [2].

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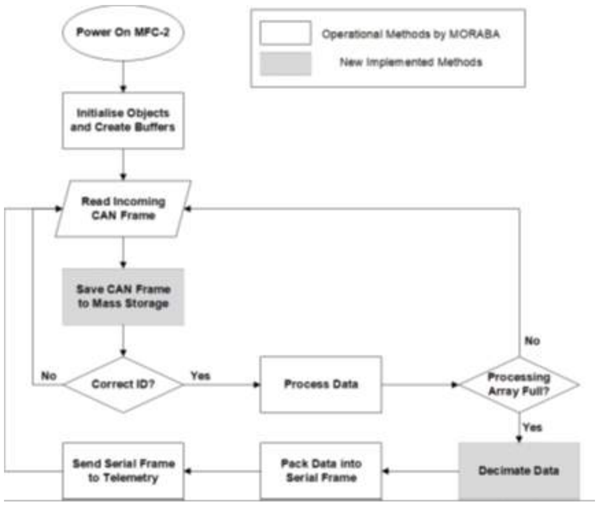

Fig. 3. Software Architecture Flowchart

Data Processing: The MFC-2 is connected to the DMS-8 and PT-100 amplifiers through an internal CAN bus for reading out and setting. The CAN message consists of three parts: a timestamp, an ID and the measurement data. To sort the data into the two classes DMS and PT100, the IDs of the CAN messages are used. This function has already been completed by MORABA and Domjahn [2]. As shown in Fig. 3, the functions "Decimate Data" and "Save CAN Frame to Mass Storage" are newly implemented. The data sent to the GCS is decimated using a buffer. The decimation rate is used as the length of a buffer. When this buffer is full, the first measurement is sent. The number of data packets to be decimated depends on the sample rate of the DMS-8 amplifiers and must be set before the rocket launch. The second function is "Save CAN Frame to Mass Storage" and the following solution was developed. Onboard the data is stored on an SD Card. The message size of a stored data packet is 18 bytes per CAN message. At a sampling rate of 1 kHz for the DMS-8 amplifier and 10 Hz for the PT-100 amplifier it results in a total memory requirement of about 80’000 kB by a recording time of 2250s. Further system data of the amplifiers and the MFC-2 are stored, but their memory requirements are less than 10% of the total data. The measured data can be read out after the flight by executing a function via the programming interface.

Rocket Signals: Since direct control by the uplink is only possible before LO, the software must run automatically. The RXSM provides the following three rocket signals for this purpose: Start of Data Storage (SODS), Start of Experiment (SOE) and Lift Off (LO). In the FLOMESS experiment the signals are implemented as follows. As soon as a signal is triggered, the voltage difference is noticed by the MFC-2. With a program loop it is checked which signal is activated. The signal whose circuit is no longer switched off is seen as activated. Then the following functions are executed in the software program in accordance with the timeline.

Downlink: The data is sent from the FLOMESS module to the GCS via the RXSM, TM, SCIENCE-NET. The requirements of the RX User Manual include the max baud rate of 30 kbit/s [3]. For the FLOMESS experiment the downlink packets are sent as 20 Byte datagrams (Fig. 4). The start and end of the data packets are predefined in the RX User Manual. In order not to exceed the baud rate, a data decimation takes place on the MFC-2, as already mentioned. The sampling rate of 1 kHz is reduced to 83 Hz and this leads to a download rate of about 27 kbit/s.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SYNC1	SYNC2	MSGID	MCNT	TIME				DATA1		DATA2		DATA3		DATA4		PAD	PAD	CRC	CRC

Fig. 4. Downlink Protocol

Uplink: The uplink transmission path differs slightly from the downlink. The commands are sent from the own GCS to the FLOMESS module via the SCIENCE-NET, the EGSE and the RXSM. The data format is equal to the downlink except the missing timestamp. The commands concerning either the amplifiers, the memory card or the MFC-2 each receive different IDs. In the data area, values can be transferred to the MFC-2

Ground Control Station

The GCS is divided into three parts: A real-time display of the downlink data, a control console and a storage of the incoming data. The ground control software will be implemented as a client-server system: A server program receives the packet data from the ground control infrastructure. It is written in the Crystal language, an improved variant of Ruby. This server program stores every received packet in a database and forwards it to a frontend running on a webserver. This frontend displays the raw data and calculated flight loads.

Realtime Display: The realtime display is used to monitor the experiment. Status values are displayed for all of them in the lower right corner. This includes the server time and status of the server, telemetry and rocket signals. The first display shows the raw data of all channels (Fig. 5). The digital 16-bit numbers of all measuring locations are plotted over time in four graphs. The upper two graphs show the measured strains. The lower two graphs show the temperatures.

Control Console: The control console is implemented like the live display via the webfrontend (Fig. 5). Besides the commands to control the amplifiers, the SD card methods can also be executed. In addition, there is the option to read out the SD card and download the data via the MFC-2 for post-flight analysis. A dropdown menu is useful for commands that pass certain values, as this reduces the number of buttons and keeps the control console clear.

Data Storage: The data storage on the GCS is used as a backup for the onboard memory card. All incoming data is stored on a web-based database. The data can be received from a server connected PC via a web browser. The page is then saved as a text file. Since the ID of the amplifier channels and the measurement data are available in the downlink data format as in the CAN data, the data can be quickly read out during the post-flight analysis and sorted according to the measurement locations.

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Fig. 5. Ground Control Station: Rawdata

IV. Calibration Phase

A. Testing

For the calibration phase, the test facilities at the Institute for Lightweight Structures are used. The aim is to calibrate each section load independently of each other. Each test take place under static load.

Axial Force: To calibrate the normal force Nx, various pressure tests are performed using a hydraulic cylinder. By means of centric or eccentric pressure different load cases have been simulated. In calibration tests with eccentric pressure, several lever arms are selected from the force introduction point to cover different bending moments. Thirty tests are carried out to describe this type of load.

Shear Forces and Bending Moments: The calibration of transverse forces (Q_y and Q_z) include the simultaneous calibration of bending moments (M_y and M_z). Therefore, the rocket structure is attached to a test bench using an adapter plate. A shear force is then applied to the structure via a hydraulic cylinder. The resulting moment can be modified by variation of the position of the experiment module in axial direction. A total of nine tests are carried out for this experiment setup, with three height variations taking place with subsequent rotation of 0°, 45° and 90°.

Bending-Torsion: The calibration of a pure torsional moment is difficult with respect of the available test equipment. To allow calibration of the torsional moment Mt, the cutouts of a dummy module are used. In contrast to the structure for calibrating shear force and bending moment, the force application have to be done in order to generate a torsional moment around the longitudinal axis. Therefore, an eccentric load is introduced by a wooden beam, which is inserted through the cutouts and loaded on one side with a transverse force. Nine tests are performed under the same variation as the shear force and bending moment calibration.

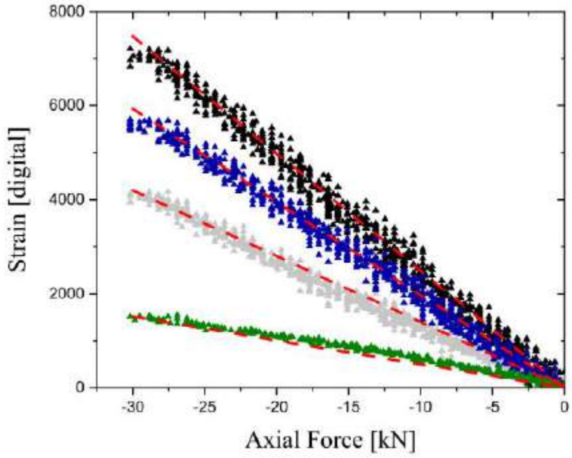

Fig. 6. Evaluation of the Strain Gradients

B. Analysis Process

After performing all the calibration tests, the measured data must be analysed in focus of the produced strain gradients. The strain gradients are required for the calculation of the matrix. The gradients are determined by linear approximation according to the assumption of linear structural behaviour. Load application and reduction result in two gradients that ideally overlap. For the evaluation of the calibration tests only the load introduction, i.e. the rising edge of the gradient, is considered. Fig. 6 confirms the correct assumption of linear structural behaviour. The transposed calibration matrix β^T can be calculated from the strain gradient of each strain measuring location and the corresponding load vector using (2). The vectors of the strain gradients μ and the loads *L* are converted into matrices by assembling the vectors column by column from the right.

$$[\beta]^T = [[\mu][\mu]^T]^{-1}[[\mu][L]^T] \tag{2}$$

In order to determine a direct deviation, the forces in the load vector of the respective calibration tests are normalized to one to calculate the calibration matrix. The resulting moments then are calculated from the normalized force multiplied by the corresponding lever arm. To be able to carry out a comparison of the individual section loads, the loads are summed over all calibration tests in which they are calibrated and then divided by this number. This is also done with the calibration loads.

C. Temperature Influence

In addition to the calibration of the system in order to be able to determine structural loads from strains, a distinction has to be made between thermal and mechanical strain in the event of an expected temperature increase of the rocket structure during flight. The disturbance of the thermal expansion is influenced by the factors of the different application and orientation of the strain gauge rosettes. By using a PT-100 temperature sensor close to each individual strain gauge bridge, correction functions for transient heating can be determined. The experiment involves heating the structure to the shut-off temperature and then cooling it down to the initial temperature.

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Tire heating blankets are used to heat the rocket structure. At the same time, the strains and the associated temperatures are measured to describe the effect of the thermal strain. The result shows that the strain gauge rosettes are influenced by temperature changes depending on their orientation. In order to consider the temperature strain, correction functions are derived from the determined strain-temperature graphs for each individual strain measurement rosette. The correction functions are a third degree polynomial. They are difficult to validate for the real flight, because they can only be confirmed on the basis of the performed tests. It is also unclear whether the functions cover a larger interval than can be tested. The determined correction functions can lead to a partial isolation of the temperature influence under combined mechanical and thermal load.

V. Failure Analysis

After a system failure of the FLOMESS module occurred during the rocket launch of the RX-25 rocket, no calculated flight loads according to the Skopinski method can be presented here as a result. Instead, a failure analysis is carried out here with the purpose of localizing the main cause and preventing such a system failure during future flights of the FLOMESS module. A failure analysis consists of the following steps [4]:

1) Information gathering,

2) Failure definition,

3) Creating a fault tree with a Fault Tree Analysis (FTA),

4) Investigation of the events with a Failure Mode Assessment and Assignment Matrix (FMA&AM)

5) Converging to the main cause.

The different steps are performed using the FLOMESS experiment as an example.

A. Information Gathering

The first step is also one of the most important. The more information about the failure that has occurred is collected, the more accurate the subsequent investigation of the failure can be. Recommended by [4],at least the following information should be collected:

- All TM recorded by ground station, including the raw and processed data.
- All recorded commands sent to the experiment
- All telemetry available from the RXSM
- All the assembly documentation

In addition, photos are used, which were taken immediately after the recovery of the RX-25 rocket and show the FLOMESS module with all connectors from different sides.

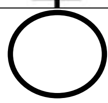
B. Failure Definition

The failure definition should describe as exactly as possible the failure as it occurred. It should be avoided to come to rash conclusions about possible causes in this step of the error analysis. The following failure occurred during the FLOMESS experiment: “*From a moment of approx. 1 second before LO no measurement data arrived at the GCS. Furthermore, no data was received during the entire rocket flight.*”

C. Fault Tree Analysis

FTA is a top-down symbolic logic model generated in the failure domain. This model traces the failure pathways from a predetermined, undesirable condition or event, called the TOP event, of a system to the failures or faults (fault tree initiators) that could act as causal agents.”[5] A fault tree consists of various events and gates that the events pass through to trigger the next event. Although many event and gate symbols exist, most fault trees can be constructed with the following four symbols: TOP or Intermediate event, inclusive OR gate, AND gate, and basic event. The symbols and descriptions of these events and gates are shown in TABLE I. Fig. 7 shows the finished FLOMESS fault tree. The complex fault tree is easier to understand because the individual events are coloured according to the categories general, hardware, software and environmental influences. Since only inclusive or gates are used, it is not required to specify the gates.

TABLE I. FTA SYMBOLS

Symbol	Name	Description
	Event (TOP or intermediate)	This is the event to which failure paths of lower level events lead.
	Inclusive OR gate	An output occurs if one or more inputs exist. Any single input is necessary and sufficient
	AND gate	An output occurs if all inputs exist. All inputs are necessary and sufficient
	Basic event	An initiating failure that is not developed further. These events determine the resolution limit of the analysis.

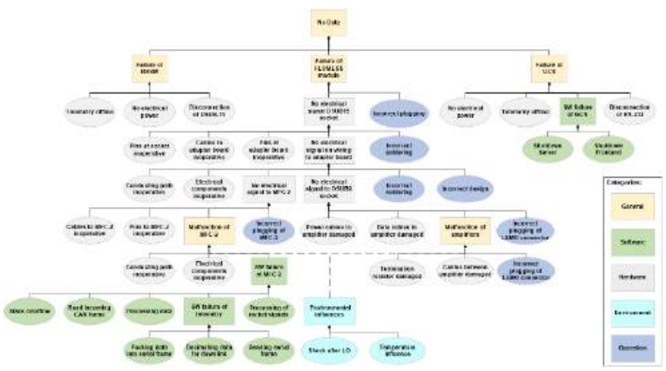


Fig. 7. FTA for FLOMESS

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D. Failure Mode Assessment and Assignment Matrix

All basic events, also known as leaves, are now placed in the FMA&AM. TABLE II. shows the possible FMA&AM for the different categories from the FTA. Assessment is simply whether the event is still a credible failure point or has been discounted by an investigation. Investigation actions should be sorted by their degree of reversibility.

TABLE II. FMA&AM FOR FLOMESS CATEGORIES

Event	Assessment	Investigation Action
Operation		1. Visual check 2. Check of documentation/data 3. Functionality test
Hardware		1. Visual check 2. Check of datasheets 3. Functionality test 4. Electrical function check
Software		1. Confirm checklist 2. Functionality test 3. Check of SW code 4. Modify parts of SW code
Environment		1. Test with different Temperatures 2. Test with shock simulation

Investigations carried out showed the following results:

1) By analysing the existing flight data and the own flight procedures it can be excluded that the failure is located at the GCS or the RXSM.
2) By the visual check and with the available postflight photos already some basic events can be excluded, e.g. incorrect plugging.
3) By functionality tests, the failure caused by hardware components can be excluded.
4) By several function tests at different temperatures, the influence of temperature can be excluded.

Therefore, the failure is in the software.

E. Converging to the main cause

In the last step, the main cause is investigated in more detail so that it can be removed in the future. If the time stamps of the last messages sent are considered, it results that at 3.5 seconds before LO the last measurement data were sent. However, the last message sent was the LO signal processed on the MFC-2. A very similar situation could be simulated in the laboratory by running the MFC-2 until apparently no more measurement data was sent. The RXSM simulator then triggered the LO signal with a delay of a few seconds. The following conclusions can be reached:

1) Not all the software fails,
2) The failure is probably related to a stack overflow,
3) The communication between MFC-2 and amplifiers seems to be interrupted.

In order to further locate the failure, the various storage operations should be investigated more closely in the future. The priority is to look at the functions for reading out the can data.

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The need for an Inclusive Space Sector: a Student Perspective

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Abstract—The UK Space Agency aims for the sector to account for 10% of the global sector by 2030 [1]. This target cannot be achieved without growing the workforce to support the sector, which will require removing barriers to accessibility for under-represented minorities, making the sector inclusive for all. UKSEDS is working to ensure that its own practices are inclusive; this paper presents UKSEDS inclusivity initiatives and demographic data, including ethnicity, gender and sexual orientation. Comparisons are made to workforces from the space and other sectors, and overall, delegates at the National Student Space Conference (NSSC) are more diverse.

Keywords— diversity, inclusion, space sector, students, equality

I. Introduction

UK Students for the Exploration and Development of Space (UKSEDS) is the UK's national student space society. The society was created in 1989 and seeks to create opportunities for students and graduates interested in space. It has almost 500 members, comprising primarily of physics and engineering university students.

A. Aims

This paper seeks to:

1. Outline the motivations for working towards a diverse and inclusive space sector;
2. Summarise the demographics of the students taking part in recent UKSEDS activities, and compare this to the sector as a whole;
3. Explain the work UKSEDS is doing to make space accessible to all;
4. Set out future plans in this area for UKSEDS

This paper serves as an update to a poster presented at the Lunar and Planetary Science Conference in Texas, 2019 [2].

A. Introduction to UKSEDS

UKSEDS is run nationally by a team of ~30 volunteers, remotely, across the UK. There are also currently 27 branches; these are space-related university societies which have affiliated with UKSEDS in the 2018/19 academic year. The main activities UKSEDS organises are outlined below:

Events and Workshops – conferences and training to inform, enthuse and upskill students in the space sector, including:

- National Student Space Conference (NSSC) is UKSEDS' largest annual two-day event which sees ~350 students attending, its location changes annually.
- Careers Launch, these events are smaller scale one-day careers conferences held for students and school pupils.
- Diversity in Space Careers (DISC), one-day conference, held at the Royal Astronomical Society in 2018, to promote equality, diversity, and inclusion in the space sector.

Competitions – Technical team project-based challenges for university students to gain problem solving experience in space related disciplines, including:

- Rover competition, each year since 2016, student groups have been invited to design, build, and test a rover. The competition spans a year, with each design phase judged by industry professionals, and a final testing day at Rutherford Appleton Laboratory (RAL) Space facility.
- National Rocketry Championships, a summer competition for student groups to build, launch and learn about hobbyist rocketry.

Advocacy – Voicing the needs of students and those in their early career in the space sector to key stakeholders, some activities carried out include:

- Speaking/participating in panels at external events.
- Writing papers outlining the student perspective on key issues for the sector.

Outreach – Volunteers taking part in science communication and public engagement.

Careers – Running the SpaceCareers.uk website, a careers resource for young people, students and graduates interested in working in the space sector.

B. The UK Space Sector at a Glance

In 2016/17 the space sector in the UK was worth £14.8 bn, accounting for 5.1 % of the global space economy [1]. The UK Space Agency aim for the sector to make up 10% of the global sector by 2030; this means that a much larger workforce is needed [1].

UKSEDS considers the space sector to include scientific and technological research, academia, non-technical areas (such as outreach/public engagement and space law) and industry. The

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space industry is split into two segments, upstream and downstream. Upstream involves activities related to the manufacture and launch of satellites and spacecraft, including the research and development stages, and any associated products, services and infrastructure. The downstream segment utilises the space technologies and data from space assets to deliver products and services such as satellite broadcasting and Earth observation. In 2016/17 the downstream segment accounted for the majority of the UK space industry's income at £12.4 bn, while upstream increased from previous years to £2.4 bn [1].

II. Motivations for Diversity and Inclusion Work

'Diversity and inclusion' is the advocation of the involvement and empowerment of individuals with different genders, sexual orientations, ethnicities and socio-economic backgrounds. This goes beyond a basic tolerance of people's differences, by aiming to understand, respect, and accept one another. Within a workforce, this can even result in the development of specific strategies and practices to support the growth of diverse groups. Here we use the term 'diversity' to mean the representation of different groups within a field or organisation, whilst 'inclusion' means the behaviours and actions that promote equality and diversity.

This is not just an issue within the space sector, but is being addressed globally by governments and other organisational bodies. In the past, United Nations agencies and others have run campaigns including "Do Something For Diversity and Inclusion" and "World Day for Cultural Diversity for Dialogue and Development" [3], in order to raise awareness around such issues. These activities lie under the UN's Sustainable Development Goals which include gender parity. The UK government has also passed several laws promoting diversity and inclusion, including the Equality Act 2010 [4] and have put in place systems to monitor metrics, such as the gender pay gap, by which companies with over 250 employees must report the disparity in wages between different genders within the company.

Across all areas of STEM, initiatives have been implemented to measure diversity within the workforce, and to advocate for a more inclusive field. For example, the Royal Society collects demographic data and found only 9% of fellows identified as female in 2018 [5]. Other charities and initiatives such as the WISE Campaign and Stemettes have been set up to address gender imbalance in STEM. The Royal Academy of Engineering established the Engineering Diversity Concordat as a means for professional engineering institutions to commit to increasing diversity. There is a need for such work as just 7.8% of engineering professionals in 2018 were from BAME (black, Asian and minority ethnic) backgrounds, this is less than the 12% for the total UK workforce [6].

Within the space sector in the UK, professional bodies and learned societies are also promoting diversity and inclusion efforts. The Royal Astronomical Society (RAS) 2016 demographics survey of the Astronomy and Geophysics research community [7] found that minorities, such as those who identify as BAME and disabled people are under-represented at all levels in the field. The Women in Aviation and Aerospace Charter was developed as a commitment to improving the gender balance in aviation and aerospace, particularly supporting women into levels of seniority [8]. Several organisations support the charter including the Royal Aeronautical Society and Women in Aerospace Europe – UK, and signatories include the UK Space Agency.

The RAS alongside the Institute of Physics and the Royal Society of Chemistry published a report in 2019 which surveyed physical scientists in the UK and Ireland to investigate the climate for LGBT+ people in the workplace. 28% of the LGBT+ respondents to this survey said that they have at some stage considered leaving their job as a result of LGBT+-related discrimination in the workplace [9]. The report made recommendations for improving the climate for LGBT+ people, for example: improved training which can tackle issues such as misgendering.

Diversity and inclusion in the workplace is not only important from a moral perspective, but could also have economic benefits. While data suggest that more diverse organisations are more likely to perform better [10] it is difficult to prove that this enhanced performance is down to increased diversity, as companies with more diverse workforces are more likely to be more forward thinking, on the whole [11]. This should not, however, deter organisations from working towards a diverse workforce, since it is clear that if barriers exist for some groups of people then the talent pool being drawn from is reduced.

Since early 2018, UKSEDS has focused many of its activities on advocating for a diverse and inclusive space sector in the UK and Europe. The space sector in the UK is less diverse than the UK workforce. People of colour, women, people with disabilities, LGBTQ+ people and those from low socio-economic backgrounds are under-represented, especially in more senior roles, both in STEM, and in the space sector. There is already a shortage of skilled workers in STEM in the UK [1]. In order to reach the expansion goal for the sector, it is clear the space industry needs to diversify.

UKSEDS believes that everyone, regardless of background, should have equal access to the space sector, and is therefore working to advocate for a more inclusive field. Most organisations focus on diversity and inclusion work with school pupils or those working within their own companies. UKSEDS acts as a gateway to the sector for many students and is championing best practice in inclusivity and reflection on its own activities, to ensure that we make space accessible to all, to make the sector inclusive and welcoming for the incoming workforce.

UKSEDS has been working to determine the demographics of its membership, by surveying participants of each activity. The objective is to identify any differences in the backgrounds of students taking part in the various categories of our events and competitions, identify reasons for this, and find out how better to support diversity in these settings. These will be monitored over the coming years, to build a picture of the demographics, and to identify any trends.

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III. Diversity Data From UKSEDS Activities

A. Methods

An optional diversity survey is part of the online registration process for anyone participating in any UKSEDS event or competition. The survey asks respondents for their gender, sexual orientation and ethnicity.

Over time, UKSEDS intends to build up a database of information about the diversity of our audience, how that is changing and to try to identify possible reasons for this.

This paper represents the first set of data that has been collected since the start of this initiative. Data from NSSC 2019, DISC 2018 and the 2018 & 2019 rover competition are displayed, alongside reference datasets.

B. Results

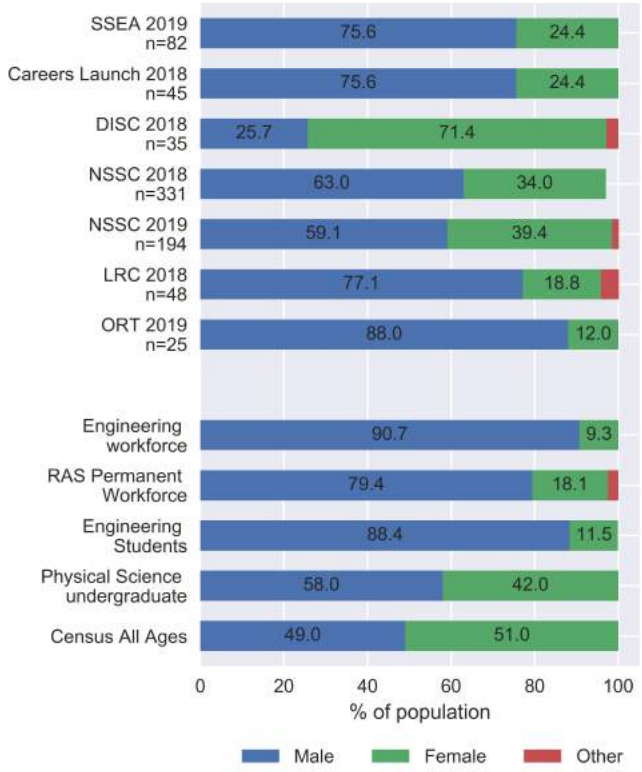

Fig. 1 The genders of people who attended UKSEDS events in 2018/19 are displayed, alongside reference datasets from refs [6, 7, 12, 13].

C. Discussion

Comparing Figures 1-3, we can see that NSSC delegates are more diverse, on the whole, than their space-related workforce counterparts. The engineering and astronomy workforces, for example, have a much lower proportion of women than NSSC had in 2019. Similarly, only 81.7 % of NSSC survey respondents identified as white, compared to 90% of the astronomy workforce.

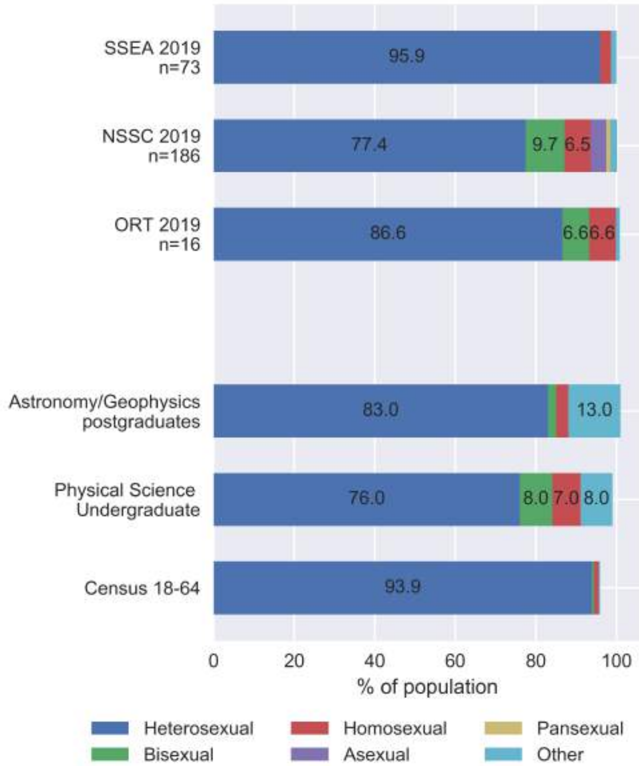

Fig. 2 The sexual orientation of delegates at UKSEDS events in 2018/19 are displayed, alongside relevant available reference datasets from refs [6, 7, 12, 13].

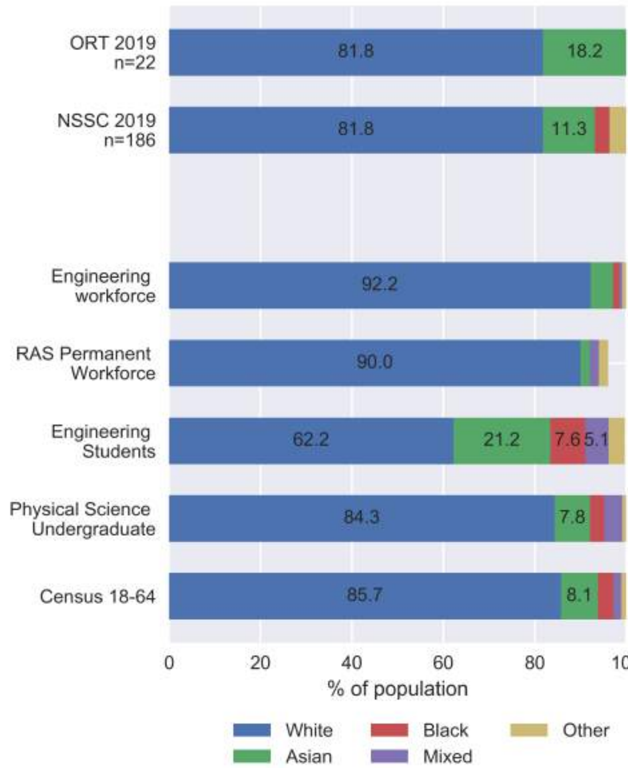

Fig. 3 The ethnicities of delegates at two UKSEDS events are displayed, alongside relevant available reference datasets from refs [6, 7, 12, 13].

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NSSC is open to all, however most attendees (~70%) are either engineering or physics students. Comparing these datasets presents difficulties and limitations when making inferences, due to the differences in surveys by external organisations. The figures shown for physical science undergraduates are from the Higher Education Statistics Authority (HESA) which collects data for all physical sciences, as a whole, rather than individual subject areas, such as physics or chemistry. This, in particular, is likely to skew the data from a gender perspective, since ~ 50% of A level chemistry pupils are girls, compared to only ~20% of A level physics pupils. It is therefore likely that, if we were to compare our data to physics undergraduates, as opposed to physical science undergraduates, the NSSC delegates would have a significantly higher proportion of women. Should this assumption be correct, it may well be the case that more women are interested in space than are interested in other areas of physics.

It is clear from Figure 1 that there is a difference in gender participation in different categories of UKSEDS events. A much higher proportion of the delegates at DISC 2018, for example, were women, compared to the participants in the Lunar Rover Competition (LRC) and Olympus Rover Trials (ORT) finals days in 2018 and 2019. DISC was a one-day conference held to champion equality, diversity, and inclusion in the space sector, whilst the rover competitions' finals days consisted of talks and technical testing of small planetary rovers. Most competitors in the rover competition are engineering students; from Figure 1, we can see that the proportion of women participating in the rover trials finals is broadly representative of the undergraduate cohort.

Looking at Figure 1, many UKSEDS events have a similar gender ratio in attendance as this symposium, however our larger scale NSSC events, as well as DISC, both have a larger proportion of women than this symposium, the third symposium for space educational activities (SSEA) in attendance. It is difficult to discuss race and ethnicity at SSEA, as there is variation across Europe as to the definitions of race vs ethnicity vs nationality. Since ethnicity pertains to shared cultural heritage, there is wide variation amongst European countries as to what counts as an ethnic group. Thus, a direct comparison can therefore not easily be made between SSEA data and other UKSEDS activities, regarding ethnicity; the authors believe a more appropriate question would have been to ask delegates their nationality and indeed UKSEDS should start asking for nationality, too, in the future. The largest issue with the dataset that has been collected to date is the limited sample size. UKSEDS has a registered membership of around 500 members, as well as event and competition attendance of around 500, which is a limited pool of people, especially when trying to understand the effects of various influences (such as inclusivity initiatives) on diversity. Additionally, reference data for the diversity of the space sector's workforce is limited, particularly on the industrial side.

IV. Inclusive Initiatives

In order to make space accessible to all, UKSEDS has been working to make its events and activities as inclusive as possible. A few of its initiatives are outlined below, along with the associated rationale.

A. Gender Pronoun Stickers

At all UKSEDS events, all attendees (including speakers and sponsors) are asked to declare their gender pronouns (e.g. she/her/hers) by writing them on a sticker, see Figure 4. This simple activity reduces the risk of a delegate misgendering another delegate, without having to ask them for their pronouns directly. Asking all attendees to use gender pronoun stickers/badges also normalises the act, so that assumptions never need to be made and the right to self-identify is respected.

B. Colour Communication Stickers

UKSEDS asks all its delegates to use a traffic light system to quickly and clearly display their preferences whilst in networking breaks. Conferences can be challenging environments, and some people may have difficulty initiating conversations with others, whilst other people may not wish to converse with others at all. This scheme is adapted from [14] and the colour code is outlined below:

- Red: someone who does not wish to be spoken to by anyone whilst this sticker is on display, they may, however, choose to approach people;
- Orange: someone who only wishes to be approached by people they know, they may, however, choose to approach other people;
- Green: someone who is happy to be approached by anyone, they may also find it difficult to approach others themselves.

Fig. 4 The gender pronoun and colour communication stickers used by UKSEDS at its events.

UKSEDS is determined to work on diversity and inclusion with an intersectional approach, and recognises that whilst this traffic light system is effective for most people to understand others' communication preferences, people who are red/green colourblind may struggle to distinguish the difference. UKSEDS is therefore going to improve these stickers through the use of patterns/graphics, to make these stickers more inclusive.

C. Diverse Speakers and Chairs

UKSEDS recognizes the importance of diverse role models and ensures that speaker lists and panel discussions at all its events are as diverse as possible. For NSSC, an equal

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female:male ratio has been maintained alongside a wide range of other backgrounds, such as BAME and LGBTQ+.

In order to encourage and build confidence in students/those in their early career, UKSEDS has incorporated a chair and co-chair system for panel discussions, whereby a less experienced person chairs the discussion alongside a person with more experience. Having a chair and co-chair system also encourages a wider range of questions to be asked.

D. Anonymous Question Submission

At NSSC, audiences are given the option to submit questions to speakers and panelists anonymously, whereby an online form specific to the session they are in. The session chairs can access these questions and put them to the speakers, giving the opportunity for questions to be asked by people who feel less comfortable asking them publicly.

E. Breakout Zones

At its larger events UKSEDS designates a room for delegates to use as a quiet space, to have a break from networking. This room is well sign-posted and delegates are able to use it at any time during the conference.

F. Code of Conduct and Reporting

UKSEDS has a clear code of conduct for delegates and volunteers at its events, to set out expectations for behaviour, to maintain a safe, enjoyable and accessible environment for all.

I. Future Plans

As previously mentioned, we intend to continue surveying diversity at our own events over the next few years, to build a clearer picture of how we are facilitating inclusion, as an organisation. We will also solicit feedback on our own inclusivity initiatives, to see how they are being received, and if we can improve our approach to these situations.

In addition to this, we would like to engage further with other organisations about how they collect their own data and promote diversity and inclusion, both within their workplaces and at public events.

V. Conclusions

As the main representing body for students interested in entering the space sector, UKSEDS acknowledges its duty to set an example of a diverse volunteer workforce and inclusion throughout all of its activities. Through this ongoing work advocating for a more inclusive sector, we have identified practice that would be useful for colleagues and stakeholders. We will continue to use and refine these, to promote diversity in the best way possible, and encourage others in the sector to do the same.

UKSEDS also strongly encourages like-minded organisations, societies and businesses to collect anonymous data on the diversity of their volunteers, staff and members and to make this available to others. This will build a wider pool of data and allow the sector to identify any barriers to the sector with more accuracy, and thus create a more targeted approach to removing them.

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Remote Sensing Payload Development for High Altitude Baloons

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***Abstract*— Remote sensing provides fundamental data about landmark characteristics. Up to date remote sensing information is vital in almost every industrial and agricultural sector. Providing such data and processing services are interesting fields for both traditional space agencies and smaller new-space companies. However there is one method of data acquisition that is not yet widely utilized. With a stratospheric balloon large areas could be covered and balloons can be launched in a frequent manner. The UPRA Project (Universal Platform for Robotics and Aerospace) is a student project with an aim to develop a reliable, widely configurable high altitude balloon platform for university research groups.**

The aim of the project is to build a proof-of-concept multi-spectral remote sensing hardware and using open source and self-developed software to analyze data provided by the payload to demonstrate that high quality and relevant remote sensing can be achieved for a comparably low price. The payload train consists of a parachute system, an avionics module, a backup GPS tracker, radar reflector, a flight termination unit, a control camera and the remote sensing module (UPRACAM), developed internally by the team. The avionics module contains the main flight computer, which provides two way radio communication, live telemetry and scientific data and also controls the payload.

A balloon-borne multispectral camera was developed that is capable to sense in visible and near infrared spectrum. The camera is made out of commercial off-the-shelf (COTS) components to keep the cost and development time low. The device has a twin-sensor configuration. The identical image sensors have a wide spectral response in the 420nm - 980nm wavelength region which makes them ideal for this field of use. The camera lenses are equipped with short-pass filter for visible and high-pass filter for near infrared image capture.

Although the camera was developed for high altitude balloon, in the future it is possible to use it in small satellite missions since the design allows to easily integrate with CubeSat frames and various flight computers. In 2019 the project had four proof of concept flights with the developed remote sensing payload, collecting almost seven hours of flight data. This might be the first step to develop regular scientific remote sensing balloon missions in Hungary. During these flights the data collected might help authorities to organize protection or salvage during floods, after hails or storms. Also valuable information could be provided to the agriculture on vegetation covered areas and inland waters.

Keywords*— *high altitude balloon, remote sensing, earth observation, agriculture

I. INTRODUCTION

Nowadays remote sensing is a crucial part of our life. Different remote sensing platforms provide information about vegetation health, crop management, floods, inland-water, forest fires or even traffic. Data provided by remote sensing platforms is vital in almost every industrial and agricultural sector.

Remote sensing services became more and more popular in the new-space industry. Companies research new possibilities in both data gathering and processing services. Stratospheric balloons could be a reasonable candidate besides the already available remote sensing platforms by providing large, frequent coverage for a reasonable cost.

This paper introduces the possible use of small balloon platforms in remote sensing applications and the development of a small sized multispectral camera designed for high altitude balloons or picosatellite Earth observation missions. Successful test flights conducted with the proof of concept device indicates that the development is worth continue and could provide a competitive solution in the remote sensing domain.

II. REMOTE SENSING PLATFORMS

Gathering remote sensing data can be performed with different platforms. Using satellites are the most common method in Earth observation programmes. However, if the area of interest is smaller other different airborne platforms can be used, such as manned or unmanned aircrafts. Parameters - such as covered area, modularity, scalability or cost effectiveness - can vary by each data gathering method. Effectiveness of a remote sensing programme can be enhanced by selecting the right platform according to these parameters. Beside the commonly used platforms there is a data gathering method that is relatively unresearched in commercial or regular remote sensing applications. High altitude balloons were one of the first remote sensing platforms but nowadays their significance is lower compared to satellites. However their application in smaller scale operations became a trending research topic among new-space companies.

As in Fig. 1 can be seen each platform performs well in at least one parameter, but these information should be handled together when a remote sensing mission is planned. Manned and unmanned aerial platforms provide high spatial resolution data due to their low altitude of operation, but they are not

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suitable to map large area. Due to the small coverage area and the need of frequent flights makes the cost per unit area of ground coverage relatively high with aerial vehicles. However these platforms usually used for one-time operations but in many areas continuous monitoring of Earth features is needed. Satellite platforms while providing lower resolution, they offer continuous or frequent coverage of an area of interest which makes the cost per unit area low. However the mission planning, development, validation, launch and control activities would increase the expenses for the overall mission which makes orbital platforms unaffordable for smaller research groups. High altitude balloons with a peak altitude of 40000 meters (operating in the stratosphere) can also cover significant area and with active altitude control it could perform the observation over the area of interest. Balloon platforms can be launched in a frequent manner to provide continuous coverage. Also there are research programmes working on continuous, actively controlled flock operation of balloons, to cover a designated area. On the basis of the cost parameter, the use of balloons should be considered. Expenses of one launch including payload mating, validation and launch activities can be solved from as little as 1000-1500 EUR for smaller sized payloads.

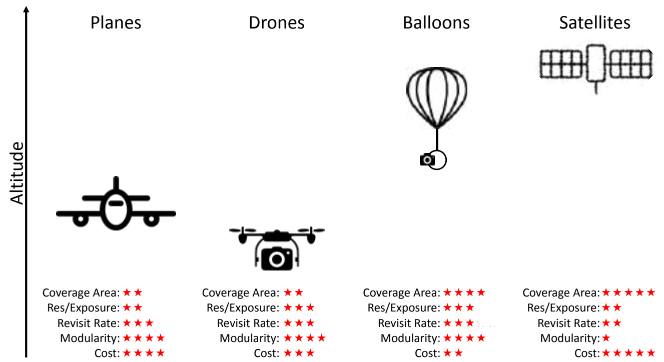

Fig. 1. Comparison of remote sensing platforms[1]

III. UPRA BALLOON PLATFORM

Universal Platform for Robotics and Aerospace (UPRA) Team of Simonyi Karoly College for Advanced Studies develops a configurable modular balloon platform. The platform is developed and manufactured by students and the goal of the project is to develop a launch platform for small science payloads up to 30 kilometers to the stratosphere. The UPRA Team is working on a launch service targeting university research groups to provide an affordable platform, launch, recovery and flight planning for their mission.

The platform has two way radio communication, live tracking, on-board data collection and data handling. The avionics module is also capable to control third party payloads and transmit science data during flight. The platform is equipped with redundant tracking system and an independent landing locator to ensure the successful recovery of the payload train.

To meet mission demands the platform is highly configurable and requires low maintenance which makes it suitable for frequent or regular stratospheric missions. It is planned to provide a standardized payload gondola to even lower the expenses and the preparation time, but if the mission requires custom made gondola also can be designed and mated with the payload train.

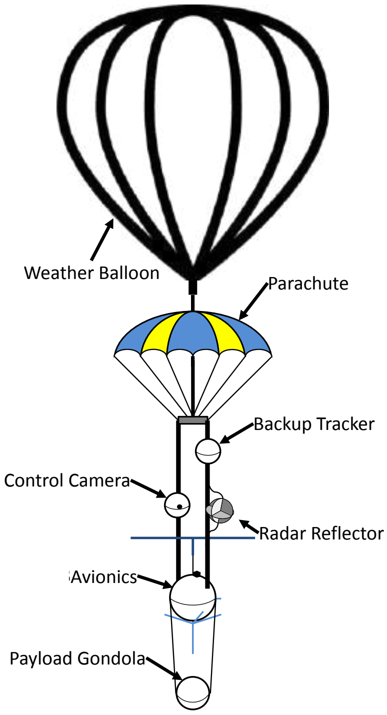

Fig. 2. UPRA payload train flight configuration[1]

Fig. 2 shows the payload train configuration with one payload gondola attached. Research is ongoing on the topic of multiple payload gondola configuration and its flight dynamics.

IV. REMOTE SENSING PAYLOAD

As technological demonstration, a vegetation monitoring remote sensing payload (UPRACAM) is developed for UPRA balloon platform. This topic has been chosen due to its low development expense and the benefits of vegetation and open water surface observation on agriculture. Other methods could provide information on carbon-dioxide footprint, urbanization and traffic or temperature change of a region. These observations would need more delicate sensors and more expensive measurement hardware. Since the goal of this proof of concept mission is to pave the road for balloon borne remote sensing, a cost effective solution was chosen.

Vegetation and open water surfaces can be observed using a multispectral camera with a near-infrared (NIR) and a visible light (VIS) channel. Measurements could be fined if the VIS channel is divided to red (R), green (G), blue (B) light.

Plants reflect mostly 500-560nm wavelength in the visible spectrum which makes them appear green. They also reflect 680-900nm light which is in the near-infrared spectrum and cannot be seen by the human eye, although the amount of

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reflected NIR light carries important information about the health of the plant. Composite image information generated from NIR and VIS camera data can help monitoring and visualize vegetation health, plant composition and the proportion of vegetation covered areas. These data sets can help agricultural planning, crop and pesticide management. Beside information on plant life, data on open water surfaces is also very important in agrarian management to monitor inland-water, canal structures and routes and to predict or calculate possible flood damage.

While plants reflects most of the near-infrared waves, open water surfaces reflects no or very little. With the same multispectral camera and image processing methods water covered areas can also be monitored. Using the composite images inland-water and flood-water area can be measured and used for crop management or property salvation.

A. *Hardware Implementation*

The sensor selected for the payload is the OV2640 CMOS image sensor which has large spectral sensitivity in both visible and infrared region (Fig. 3). The remote sensing multispectral camera is using two identical image sensor modules, one for visible light and one for near-infrared. A 800nm shortpass filter is used on the visible module to cut the higher wavelengths, while a 800nm longpass filter is applied on the NIR module to block the visible and UV, short wave light.

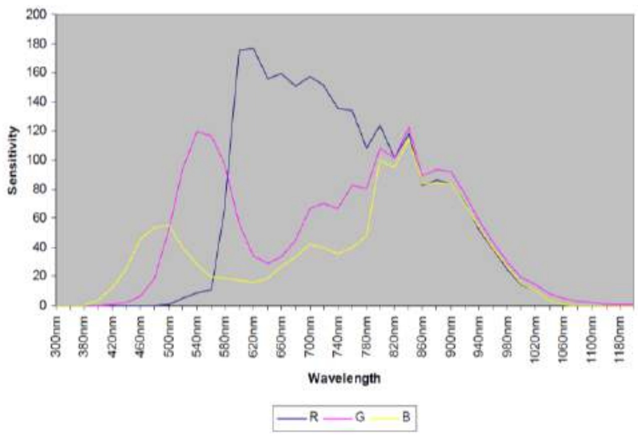

Fig. 3. OV2640 Spectrum Response [2]

The proof of concept model (Fig. 4) is based on two Arducam Mini 2Mpx modules with M12 (S-mount) lens mount, internal image buffer as temporary storage and OV2640 image sensor. The modules have separate image buffers which makes them suitable for simultaneous photo shooting. The NIR and VIS images are taken at the same time, stored temporarily on the sensor modules and stored on a non-volatile storage.

An Arduino compatible Microchip Atmega328p microcontroller is used to control and configure the sensors, handle the non-volatile storage and the file system. The control board is also provides power and data connection with the platform, the camera is developed to provide housekeeping data, low-resolution images for telecommunication and the possibility to set image properties by the ground control.

An SD Card is selected as non-volatile storage with FAT file system. The images saved on the SD Card with a running number and a channel indicator. Beside the pictures, the camera also stores control and configuration information on the storage. Prior flight it is possible to set the frame rate, resolution, mirroring, white balance and exposure by the configuration file stored on the SD Card. The running number is increased and stored after every frame taken. This prevents to overwrite older images during unplanned restart of the camera.

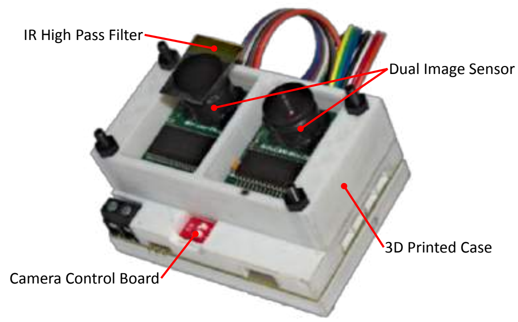

Fig. 4. UPRACAM Remote sensing camera prototype[1]

The enclosure of the camera is not larger than a typical action camera. It is 3D printed and designed to be able to be connected to passive and active stabilization systems. Currently during the test flights the camera was hanging at the end of the payload train without any stabilization or attitude control.

Since all used hardware elements are commercial-off-the-shelf (COTS) components the validation of the payload is a crucial part of development and flight operations. To ensure maximum reliability the UPRACAM is tested after every small step of development or calibration. Environmental tests were also run in thermal chamber at -50°C temperature. Prior flight, the a usual pre-flight smoke test is run on the camera module, and every integration step is followed a short validation process to check the proper operation of the camera.

V. Image Processing

Composite images are generated from VIS and NIR images using various image processing techniques. The processing can be performed by hand, but due to the large amount of data gathered during a flight it is worth to use automated processing algorithms. Two transformations were selected for further research in the project. NRG false coloring to highlight vegetation and Normalized Difference Vegetation Index (NDVI) visualized with color composite techniques.

The first step of both NRG and NDVI generation is to overlap the images. Since the NIR and VIS images are taken with different sensors the two pictures are never be fully identical. To perform an appropriate overlapping, calibration data should be provided. Lens calibration is a manual process when multiple images taken from multiple angles with a test pattern.

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The automated image processing algorithms are still under development in the time this paper is written. For the development, OpenCV libraries are used offering calibration recommendation, overlapping base functions and bit wise image processing methods. The image processing end product is planned to be a user friendly, configurable, modular software that will be able to handle different image transformations based on typical remote sensing application, and can be used on with various remote sensing payloads.

A. NRG False Coloring

NRG a false coloring method visualize the NIR light information and highlights the vegetation on composite images. The name 'NRG' refers to the color channels used in the image which are near-infrared (N), red (R) and green (G).

The blue channel of the VIS image is completely discarded because shortwave light scatters in the atmosphere making the processed image blurry and not containing useful information on vegetation and open water covered surfaces.

In an NRG false colored image vegetation depending on types and conditions, appears in different shades of red. Due to higher green band reflectance clear water appears dark-bluish while turbid water appears cyan as a result of higher red reflectance caused by sediments. Depending on their composition bare soil, roads and buildings appear in various shades of grey, blue or yellow (Fig. 5).[3]

Fig. 5. NRG false color composite image of Déli Pályaudvar railway station

B. NDVI Heatmap

To measure vegetation health and density the Normalized Difference Vegetation Index (NDVI) is used which is calculated by equation (1). NDVI is varies between -1.0 and +1.0 where the more healthy, dense vegetation is indicated by a more positive value. Open water and snow covered surfaces are represented by values close to -1.0 since very little of no NIR light reflected by these areas.

NDVI is an index which measures the vegetation density and condition. It is influenced by the fractional cover of the ground by vegetation, the vegetation density and the vegetation greenness. It indicates the photosynthetic capacity of the land surface cover.

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

Fig. 6. NDVI heat map of Déli Pályaudvar railway station

NDVI computation is a pixel wise transformation. The generated data can be visualized as a heat map (Fig. 6), where light areas show vegetated areas and darker shades indicates non vegetated surfaces.

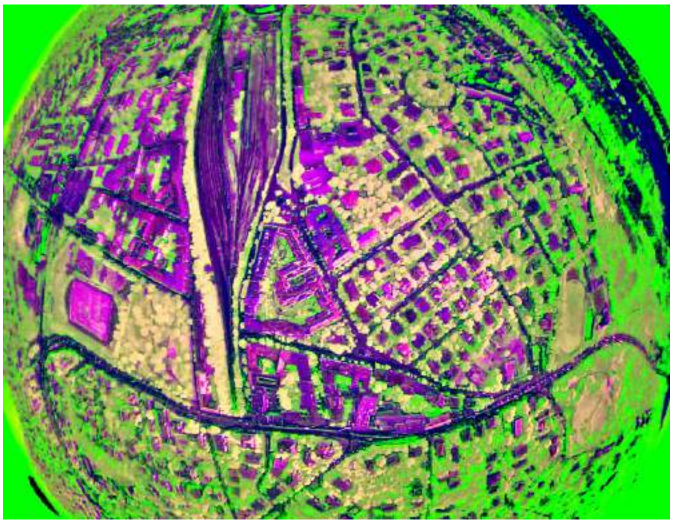

Fig. 7. NDVI Color Composite image of Déli Pályaudvar railway station

NDVI information combined with other bands captured by a multispectral camera will form a color composite image that helps differentiate vegetation types. In Fig. 7 NIR band is assigned to the Red (R) channel, NDVI to the Green (G) and green band (of VIS) is assigned to the Blue channel. In this type of composite at least three types of vegetation can be discriminated: Green areas with dense, closed canopy trees,

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bright yellow with bushes or less dense trees and golden yellow areas covered with grass. Dark blue and magenta areas indicate non vegetated surfaces.[3]

VI. Test Flights

This year four test flights were performed with the multispectral camera prototype. The first two flights were shakedown tests with only VIS imaging. While the third and fourth were full featured flights. These flight events were originally planned in the Technological Demonstration Missions (TDM) which is a programme restricted to UPRA hardware and the goal is to provide flight time and testing opportunity for in-house developed components. TDM payload could also be connected to Fly With Us (FWU) payload train if the third party payload makes it available and not forbidden by the payload developers.

A. VIS Only shakedown test

Two flights were performed in March and April as part of the Technological Demonstration Missions (TDM) programme. The goal of TDM-1 and TDM-2 missions was to test the camera electronics and insulation in real flight condition. During the test flights both sensor modules were equipped with stock lens which reduced the performance of the payload to VIS only operation.

Both tests were successful; the payload was recovered and was operational after flight.

TDM-1 was a mid-altitude flight with the peak altitude of 14000 meters and 2 hours of flight time. Image data gathered was in focus on both sensors and due to the sunny weather conditions they were also clear with minimal or no clouds appearing in the pictures.

TDM-2 was a long duration, high altitude mission with a peak altitude of 33000 meters and 5 hours of flight time. Images taken were high quality, but due to the cloudy weather pictures taken at higher altitude were only showed small portions of landscape.

B. NIR-VIS Wide angle

After the successful shakedown tests the stock lenses were replaced with wide angle infrared capable optics. A 850nm longpass filter was added to lens of the NIR sensor while the lens of the VIS sensor left bare. The replacement procedure was performed in a 'grey' lab area to provide minimal contamination on the sensors.

Two test flights were conducted in June and early August with the full featured camera. Both flights were successful, the payload train was recovered and on-board data was retrieved.

TDM-3 was a mid-altitude flight with the peak altitude of 16000 meters and 2 hours of flight time. Images taken during the flight showed that further focus calibration would be needed on both sensors as the images appear less sharp than expected although manual image processing methods presented acceptable composite pictures of the surface.

The flight in August was a part of the Fly With Us (FWU) programme to provide flight opportunity for third party payloads. FWU-2 was a multiple payload flight with the peak altitude of 31400 meters and 2 hours of flight time.

Processing of FWU-2 flight data is still in progress in the time of writing this paper, but preliminary results show the remote sensing payload performed well. As in Fig. 8 a). can be seen the VIS image is desaturated and low on contrast which is the result of the missing 800nm shortpass (infra cut) filter. This effect can be corrected during composite image generation. Manual image processing supplemented with automated overlapping shows promising results in NRG false coloring and NDVI composite generating.

Fig. 8. a) VIS image (left), b) NIR image (right)

VII. Summary

With a stratospheric balloon remote sensing activities could be performed cost effectively in a frequent manner. Each balloon flight could cover large areas with the possibility of pin point observation. Currently UPRA Team is able to keep a two week return time if no changes required on the payload configuration which could be lowered using multiple, identical payload-trains. This could be applied for short term remote sensing campaigns that targeted to collect frequent data on a designated area.

The UPRACAM proof of concept remote sensing payload shows that developing an affordable small sized multispectral camera is possible and could be the backbone of vegetation and water observation missions. The data collected could help in crop management and agricultural planning while also could be an aid to authorities during floods, after hail or storms to organize protection or salvage.

Keeping in mind the safety, scalability and modularity of the balloon platform, the information and experience gathered during the test flights provides us guidance for adding features and functions to the UPRACAM remote sensing payload and improve the reliability of the platform..

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Rapid Mission Concept Development at the 2019 Caltech Space Challenge: A Small Lander Network Studying the Habitability of Enceladus

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Abstract— **The 2019 Caltech Space Challenge was a one-week intensive mission proposal challenge that brought an international group of 32 post-secondary students from various disciplines to design multi-lander mission concepts for Enceladus. The students were divided into two competing teams of 16, Team Voyager and Team Explorer. In this paper, Team Voyager describes their process and challenges in conceptualizing the winning mission proposal (SILENUS) of an orbiter and a network of landers. The final mission architecture proposes a mission where the science data return lasts just over one year and sends an orbiting satellite housing science instrumentation to Enceladus, dropping off four penetrating seismometers to the surface of the icy moon. In our paper, we provide an overview of our high-level mission design, an analysis of team structure and dynamics, the resources utilized by the teams to assist with mission conception, as well as the challenges and learning outcomes of the week as a framework for future rapid mission concept development.**

Keywords—Caltech Space Challenge; Enceladus; Seismometer

I. Introduction

The Caltech Space Challenge brings 32 talented and highly motivated undergraduate and graduate students to participate in a 5-day international space mission design competition. The challenge is a unique opportunity for young and enthusiastic students to build technical and teamwork skills, interact with world-renowned experts in space exploration and connect to like-minded peers from across the globe. The participants are split into two teams of 16 students each, aptly named Team Voyager and Team Explorer. Both teams are mentored by industry experts, as well as researchers from NASA and academia to design their mission concept from scratch. At the end of the week, one winner is selected by a panel of judges from leading aerospace organizations, including NASA, Northrup Grumman, and Lockheed Martin for the 2019 challenge. The winners of the challenge, Team Voyager, present in the remainder of this paper, mission SILENUS: Spectrometer Investigating the Livability of Enceladus with a Network Using Seismometers. The paper is structured as follows: to begin, a justification as to why a mission to Enceladus was chosen, then an overview of the SILENUS mission from an engineering, science, and systems engineering perspective. Following the SILENUS mission, the team formulation strategy and available resources provided by the Caltech Space Challenge will be detailed. Challenges related to interdisciplinary teamwork and management are discussed, concluding with post-challenge learning outcomes.

II. Background: Why a Mission to Enceladus?

According to the Planetary Science Decadal Survey in 2011[1], a primary unanswered question is if "beyond Earth [there] are contemporary habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life and do organisms live there now?". This question has intrigued mankind for centuries and therefore is not surprising that the search for life in our solar system is one of the drivers for space exploration[2].

While in the early days of solar system exploration we hoped to find clues to answer the question of extraterrestrial life within the habitable zone, recent evidence of subsurface water reservoirs in the moons of the outer solar system[3] have shifted our attention to the satellites of gas giants in the outer solar system like Jupiter and Saturn. In particular, Cassini discovered that Saturn's moon Enceladus, an object initially thought to be a geologically dead body is one of the most likely harbours of contemporary extraterrestrial life. Cassini's measurements not only reported evidence for a differentiated interior structure with a subsurface water ocean possibly in contact with the rocky core[4], it also discovered geyser-like jets in the south polar region of Enceladus, dubbed Tiger Stripes[5]. These jets vent water vapor and solid material from the

[1]https://solarsystem.nasa.gov/system/downloadable_items/784_Planetary_Science_Decadal_2013-2022.pdf
[2] Background adapted from: http://www.spacechallenge.caltech.edu/description
[3] Khurana 1998, Postberg et al. 2011
[4] Postberg et al. 2011; Less et al., 2014; Hsu et al. 2015; Thomas et al. 2016
[5] Porco et al. 2006

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interior ocean into space. During close flybys, Cassini's mass spectrometer detected complex organic compounds contained in the plumes. This finding fueled speculation about the presence of life in Enceladus' subsurface ocean, but Cassini's instrumentation was not designed to detect life, leaving this significant question to be answered by follow-on missions.

Ideally, probing Enceladus for the presence of life means accessing not only its plumes, but also the most likely location of indicative biomolecules: the surface orifices of its jets, located in the south polar Tiger Stripes region. Given the incomplete knowledge of Enceladus' surface and its plumes, a classic single-lander mission seems too risky. But what if the risk could be spread among multiple small, cost-effective landers? This was the driving question behind the 2019 Caltech Space Challenge.

III. SILENUS Mission

SILENUS is a New Frontiers class mission proposal that investigates the habitability of Saturn's moon, Enceladus. The programmatic constraints on the mission concept as set by the challenge were the following:

1. Land as close as possible to the plumes' sources
2. Use a collection of small landers/rovers
3. Target a New Frontiers class mission arriving at Enceladus between 2036 and 2042
4. Comply with planetary protection guidelines
5. Launch the mission with one SLS-type launcher (excluding cost of launch)

The proposed mission timeline, as shown in Figure 1, is such that in 2028, the SLS vehicle will be launched from Earth, arriving at Enceladus 13 years later with a series of gravity assists from Venus, Earth, and Saturn.

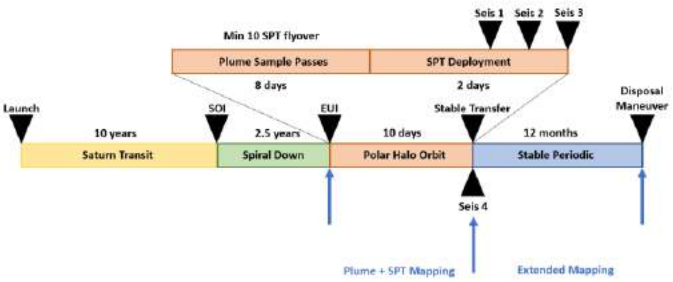

Figure 1: SILENUS Mission Timeline

Together with the orbiter and science payload, SILENUS will enter an orbit around Enceladus where a network of penetrators will be deployed to Samarkand Sulcus and the South Polar Terrain (SPT), the main regions of interest for this mission. The plume ejecta will be investigated with a mass spectrometer onboard the orbiter, and the network of seismometers will be deployed to the surface of Enceladus with the purpose of understanding the tomography. The data collected from this mission will be a transformational advance in understanding more about the geological features of icy moons in our solar system as well as an opportunity for collaborations with academia, industry and the public.

A. *Science Objectives & Instrumentation*

After constructing a science traceability matrix, the following primary scientific objectives were chosen in decreasing order of priority:

1. Characterize the organic chemistry of the plume ejecta;
2. Characterize the inorganic chemistry of the plume ejecta;
3. Constrain the age, structure, and exchange pathways of habitable environments.

In order to achieve these objectives, the cost constraints, hazards, and engineering challenges of surface operations were taken into consideration and a remote-sensing focused mission was selected. This encompassed an Enceladus orbiter with four seismometer penetrators, to be spread across the surface of the moon (one in the North and remaining three in the SPT). Remote science instrumentation included a mass spectrometer, capillary electrophoresis system (CES), an ion-selective electrodes wet chemistry lab (ISE), and laser altimeter. For in-situ science, a context camera and seismometer network were chosen to be deployed from the orbiter. The science-selected landing site is shown in Figure 2. The circles represent selected landing sites categorized broadly by hazard level (green is least hazardous, yellow is more hazardous, and orange most hazardous). Circles outlined in white are final selections and black outlines indicate backout landing sites. Selected high resolution Cassini imagery is overlaid.

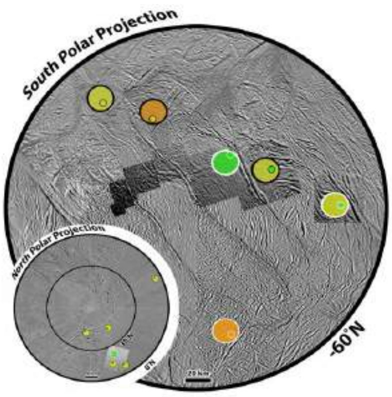

Figure 2: Landing Site Selection

B. *Engineering Constraints*

From an engineering perspective, the orbiter was modelled closely after previously successful missions, specifically the Cassini spacecraft. The key difference between Team Voyager's architecture and Cassini, is the use of solar panels as the power source, instead of radioisotope thermoelectric generators (RTGs). Solar panels were ultimately chosen by the team as they provided the same amount of power to the orbiter, with half the cost of an RTG, a crucial decision that factored in heavily with the judges' choice of winning proposal. The penetrators were modelled ballistically-shaped, such that upon impact with Enceladus' surface they would

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successfully penetrate the surface to partially submerge the seismometers housed within. Figure 3 shows the modelled design of the proposed orbiter, and Figure 4 shows the seismometer penetrators (four in total). Flight heritage and technology readiness level (TRL) were key factors for selecting the subsystem architecture and components, as a New Frontiers mission budget does not allow for a large sum towards prototyping and development of technology. The subsystem equipment onboard the orbiter have a TRL between 8-9 (with 9 being the highest), and the penetrator components chosen have a TRL between 3-5, due to the lack of pre-existing technology utilized in prior space missions for this purpose.

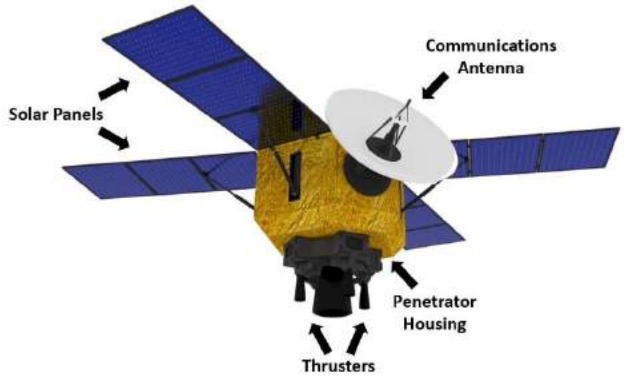

FIG 3: SILENUS Orbiter

FIG 4: SILENUS Penetrator

C. Budgets

The preliminary mass budget for the orbiter and penetrators was done through first-order approximation using *Space Mission Engineering: The New SMAD* [1] and past reports from Cassini. Sizing to our model and mission constraints resulted in a total mass of 890 kg for the orbiter and 15 kg for each penetrator (including all subsystem components). Knowing the feasibility of solar panels and their power generation capabilities (370 W), allocations were made to the major subsystems to estimate total power needed.

The mission cost budget was prepared assuming no launch costs, as instructed in the challenge, and a 30% margin on all other costs (following NASA protocol). Based on anonymized past missions and historical data, all output phases A through D using Fiscal Year 16 as a benchmark showed our total costs at $770 million, which is well within the budget of $1 billion including the reserves. The budget included costs for various items such as project management, safety and mission assurance, mission operating systems and ground data systems with the largest portion set aside for flight systems and payload. Costs for labor and time involved for ground assessment post-launch were also included. Breaking down the flight system costs, excess from the science payload was instrumental in meeting our budget for the orbiter and penetrators. Several major decisions for power generation (i.e. solar panels vs RTGs) were based on the availability of extra funds. All spacecraft component systems such as telemetry & tracking, attitude determination and control, power, structures, among others were fit into the budget with cross-checks done individually for each subsystem based on science/surveillance mission types and their nominal costs by weight, mass, and power.

D. Planetary Protection Measures

Planetary protection is defined as a set of practices to:

1. Not contaminate any planetary bodies outside of Earth
2. Prevent any contamination of Earth from exo-earth material

Following Cassini's discovery of Enceladus's ocean, "the probability of inadvertent contamination of an ocean or other liquid water body" must be reduced to less than 10^{-4} per mission (NPR 8020.12D, Sec. 5.4) [2]. For SILENUS to follow planetary protection measures, the orbiter must be destroyed at the end of the mission to avoid any contact with Enceladus or other regions of interest. Drawing from the proposed mission "Testing the Habitability of Enceladus's Ocean" (THEO) [3], we proposed to crash the orbiter into Tethys, a nearby moon that has been previously determined to be inhospitable to life. It was this decision, combined with the self-imposed budgetary constraints set by team Voyager, which the judges deemed enough to grant our team the winning proposal.

IV. MISSION DESIGN WORK AS A TEAM

A. Team Structure

Following the introductory session and team building workshop, the teams split to get acquainted with their members. A brainstorming session was used as an icebreaker, where each member listed their expertise and skills they could contribute towards the challenge. This exercise allowed for a preliminary grouping into Science, Engineering and Management sub-teams. As the week progressed, lines of communication were required between the science and engineering sub-teams and the division of work was crystallized. The Science team focused on the science objectives and data collection to be accomplished throughout the mission. The Engineering team designed the means to achieve the science objectives and successfully complete the mission. Each sub-team was assigned a systems engineer, with a third systems member designated to the management and coordination between sub-teams. Systems engineers were also in charge of ensuring the constraints were met and played a pivotal role in project management and completing the deliverables. A designated Team Voyager liaison that relayed information between the team and the challenge co-chairs was also utilized.

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B. Mentorship, Workshops, and Techniques for Concept Creation

Mentorship was a huge part of the Caltech Space Challenge, and one of the most valuable take-aways for participants. Mentors from academia, past Space Challenge participants, and industry provided feedback on design work and general support to both teams throughout the week. NASA JPL dedicated a significant amount of time to this, as the teams spent the first full day of the Space Challenge at their campus; half the day for teams to learn mission proposal design and collaboration techniques, and the other half as a tour of the facilities. Figure 5 captures an exciting stop on the tour at the NASA JPL Mars Yard with their model of the Curiosity rover. The day acted as both a learning and inspiration opportunity.
The workshops run by JPL included:

1. "Getable" Science Stories: Inspired by Pixar, the concept of storytelling involves six sentences[6]. Pixar's storytelling method can be applied to space missions, by breaking down a mission proposal into six sentences, such that an entire team of differing academic disciplines understand the mission objectives and goals. The concept storytelling involves six sequential sentences (Fig. 6), and can be used to outline any mission:
    a. Once upon a time there was…
    b. Every day …
    c. One day …
    d. Because of that …
    e. Because of that …
    f. Until finally …
2. Introduction to the A-Team: The Architecture-Team at JPL consists of a group of people responsible for coming up with new mission proposals for NASA based on the mission constraints given to them. Specific topics taught by the A-Team included: cost analysis, science return diagraming, and science traceability matrices; key lessons used extensively throughout the week by the team [4].

FIG 5: Team Voyager at NASA JPL Mars Yard

6 http://www.openculture.com/2013/03/pixars_22_rules_of_good_storytelling.html

In addition to the mission design-based workshops, team building and management presentations were also included on the opening night of the Challenge. Nigel Angold, of Angold Consulting, provided valuable insight into the structure of a good team, and the required phases each team must go through in order to be successful. Nigel was a continuous support system for Team Voyager, and assisted with disagreements in a non-judgmental, objective way. For Team Voyager, it was important to be able to have a third-party resource for conflict resolution, as will be discussed further in the Challenges section. Daily lectures related to space mission design, background science of Enceladus, and robotics engineering were hosted at Caltech with presenters from academia and industry. The lectures served as an additional knowledge resource to assist teams with their proposals, with time set aside at the end of each lecture for participants to ask the speakers questions.

FIG 6: Team Voyager Storytelling using 6 sentence exercise

V. Challenges

Among the obvious challenge of coming up with a mission proposal in 5 days for a panel of the space industry's top professionals that Team Voyager overcame, there were many others. Miscommunication was a constant challenge to deal with, due to the unfamiliarity of the team members with one another at the conception of the week, the wide variety of academic backgrounds among team members, and the high-stress environment. Systems engineers were delegated for the Science and Engineering teams and acted as a communication channel between the two teams, which assisted with deciphering what the Science team wanted to achieve and what solution the Engineering team could provide. Sub-team liaisons were extremely helpful for Team Voyager in managing conflict resolution between members, where the likely source of the disagreement arose from a misunderstanding.

The dependence on outside resources provided by the co-chairs with respect to access to prominent researchers, industry experts and specific mission-related constraints proved to create difficulties for the team. As plans were being finalized, a new hypothetical risk would arise during discussions which caused setbacks prior to achieving clarification with outside sources. With an already limited

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amount of time, this led to sleepless nights in trying to achieve a plausible solution and completing the deliverables. Related to this, the dependency of each sub-team on one another and the need for concurrent engineering and design techniques required the constant use of the team liaisons to facilitate open communication when mission critical changes were made. An example of this in use was the late-week increased mission length proposed by the Science team, which required a re-working of the power budget by the engineering team to ensure enough power for the longer duration mission. The large team size also created an environment with 16 different opinions that needed to be given the opportunity to be shared. This not only extended the length of discussions in an already time-sensitive environment, but also led to many instances of opposing ideas, which would take time to reach a consensus between. In particular, the Science and Engineering sub-teams had to balance between what science objectives were critical to the mission to be accomplished, and what was possible to achieve with the engineering design. With miscommunication between sub-teams, rising tensions would then create situations where systems engineers would need to objectively take sides and prioritize based on budgeting, time, and mission objectives. Ideally, time must be managed in order to complete a task of this grandeur, and with many perspectives, it was difficult to come to a consensus and stick to the schedule. As mentioned, third-party mentors as well as the systems engineers took on the role of assisting with the management of constructive conversations, and with assurance from past years' participants, the team understood that the pace we were at was to be expected. Moreover, rather than framing the wide variety of opinions as detrimental to the team success, Team Voyager was able to truly consider every aspect of the design and scientific objective and came up with a well-thought-out mission concept with an abundance of evidence supporting why each choice was made. These opinions led to a thorough mission proposal that was ultimately selected as the winning option.

VI. Post-challenge and Learning Outcomes

Following the challenge, participants were encouraged to share what they learned, and employ the techniques and tools utilized throughout the week in their academics and extracurriculars. Engineering team member Kelsey Doerksen ran a workshop for the University of Western Ontario's CubeSat team, based on the rapid brainstorming technique taught during the half-day JPL sessions. Undergraduate and graduate students were divided into pairs and given one-minute brainstorming sprints to come up with the components and required performance metrics for each of the CubeSat subsystems. Team member Julia Di, Engineering team member, has utilized techniques learnt at the JPL workshop during her robotics internship at JPL. Erica Nathan, Science team member, used the 6-sentence exercise with the undergraduate group in her lab, facilitating the activity to help with abstract writing. Yun-Hang Cho, team member of Explorer, spoke about his learning experience to his university. Similarly, Katiyayni Balachandran, systems team member for Voyager, presented on this challenge to her university through Students for the Exploration and Development of Space (SEDS) to encourage student participation in the future.

VII. Conclusion

The Caltech Space Challenge is a rewarding, challenging, and unforgettable experience for all participants involved. It is a unique opportunity for students to get real, hands-on space mission design experience in a fast-paced environment with like-minded individuals. Participants can use what they have learnt throughout their academics in a practical way, to prepare them for future careers in space mission design. In particular, this year's topic inspired team members to continue research in icy moon exploration.

VIII. Acknowledgements

Team Voyager would like to thank the organizers of the 2019 Caltech Space Challenge, Simon Toedtli and Fabien Royer, for the amazing experience throughout the week. We would also like to thank Team Explorer, for pushing us to produce our best work, and for the friendly competition and comradery. Team Voyager would also like to thank all of the mentors, industry members, sponsors and volunteers, who took time to share their knowledge with the participants of the Space Challenge and make it an unforgettable week. The list of mentors include: Florian Kehl, Hayden Burgoyne, Ilana Gat, Jason Rabinovich, Kristina Hogstrom, and Kristjan Stone (NASA JPL), Nigel Angold (Angold Consulting), Thibaud Talon (Caltech), the speakers: David Murrow (Lockheed Martin), Jaakko Karras, Jean-Pierre de la Croix, Kalind Carpenter, Morgan Cable, Randii Wessen, Steve Matousek, Damon Landau, and Tom Nordheim (NASA JPL) and Thomas Heinsheimer (Aerospace). Finally, we would like to thank the panel of judges for their critical evaluation and for motivating us to consider all possibilities.

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Multi-physics design of a truncated aerospike nozzle for an ammonium perchlorate solid fuelled hobby rocket

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The performance of a rocket is highly dependent on the propulsive efficiency of its engine. Through the use of conventional bell and conical nozzles it is only possible to achieve high efficiency at a single external pressure design point whereas the aerospike concept is able to achieve high efficiency throughout the rockets flight regime. The external pressure of the nozzle of a hobby rocket is variable and primarily dependant on the velocity of the rocket due to aerodynamic bluff body effects. In this research a truncated aerospike nozzle was designed using the Angelino approximation method at the point of minimum external pressure, measured at 75 kPa. It was calculated that the increase in nozzle expansion performance would provide an increase in thrust of 0.325% when compared to the conventional Cesaroni conical nozzle operating in the same aft flow conditions. These promising results indicate that further work should be carried out on the design and integration of the nozzle into the body of the rocket, including nozzle cooling and ablation rates as well as nozzle mass reduction.

Aerospike, Truncated Aerospike, Angelino Approximation, Hobby Rocket

I. Introduction

Primary limiting factors of rocket performance are vehicle weight and thrust, both of which are impacted by propulsive efficiency. High efficiency in transforming the chemical potential energy of the propellant into jet energy effectively increases the energy density of the propellant and is therefore a highly effective method of increasing performance margins. A pivotal limitation in the propulsive efficiency of a rocket is the efficiency at which the nozzle transforms the potential energy present in the post-combustion exhaust into kinetic energy responsible for the momentum transfer to the vehicle via the supersonic Prandtl-Meyer expansion mechanism. Therefore, optimum efficiency in this transformation process is highly desirable. Conventional bell and conical nozzles are only able achieve high efficiency at a single external pressure design point. This is conventionally the highest external pressure experienced by the nozzle due to concerns of exhaust flow separation leading to nozzle instability [6, 8].

External pressure of the nozzle of a hobby rocket is variable and dependant on the velocity of the rocket due to aerodynamic bluff body effects. Through successive expansion and compression shockwave interaction with the exhaust, the aerospike nozzle is able to operate efficiently from launch to maximum velocity. Reference [2] demonstrated this in 2004 and stated that the gas properties of the motor exhaust used in their research were 381.9986 J/Kg K for the specific gas constant and 1.194 for the ratio of specific heats. These values were from a modified version of the 150mm Cesaroni ammonium perchlorate motor. This motor was manufactured without aluminium agglomerate so as to avoid the complexities of multiphase flow through the nozzle. It is important to note that the motor used in the current study, a Cesaroni two grain Blue Streak, has an aluminium agglomerate additive however the proportion of this additive is not quantified by Cesaroni due to the commercial nature of this motor. The gas properties reported by [2] in conjunction with the thrust and mass flow rate obtained from the Cesaroni Pro 29 Catalogue [3] allowed calculation of the motors' internal gas properties by [4]. These are shown in Table 1.

TABLE 1: Cesaroni Two Grain Blue Streak Motor characteristics [4]

Variable	Value
Chamber Pressure (Pa)	4958168.39
Chamber Temperature (K)	2029.63
Thrust (N)	83.1
Mass Flow Rate (Kgs^{-1})	0.0396

Designing a nozzle traditionally relies on the method of characteristics applied to the Prandtl-Meyer expansion theory, proposed by [5]. This is complex and [1] provides a simplified mathematical approximation of the method of characteristics applied to an aerospike nozzle known as the Angelino approximation. Reference [1] states that his method produces a nozzle geometry that closely approximates the geometry produced by the method of characteristics, this has however been challenged by [7] due to the increased curvature of the expansion spike when compared to the two dimensional kinetics model used in the work done by [7]. An increased

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curvature represents a loss in nozzle expansion efficiency which should be borne in mind when discussing relative nozzle efficiencies of the designed aerospike and the standard conical nozzle.

II. Methodology

Fundamental motor properties for the Cesaroni two grain blue streak motor were obtained from the work done by [4] using the general equations of thrust, gas velocity and Mach number presented in Rocket Propulsion Elements [8] as well as the gas properties presented in the work done by [2]. To introduce the aspect of multi-physics optimisation of the nozzle design the external experienced pressure was found using a StarCCM+ simulation of the rocket in the work done by [4]. Thus a pressure of 75kPa was found at a maximum velocity of 300 ms-1. This is the minimum pressure at the base of the rocket due to bluff body effects, the dominant pressure effect due to negligible pressure change over the rockets maximum operating altitude of two kilometres. As at this design point the expansion ratio is much less than the maximum expansion ratio a truncated aerospike design was sought in order to reduce nozzle mass.

Using the work done by [1] a Matlab code was developed to model the ideal expansion geometry of the spike. This relies on iteratively changing the Match number of the exhaust gas and computing the location of the surface impingement of approximated characteristic lines. The Mach number of the exhaust is varied from one (at the nozzle throat) to the exit Mach number calculated earlier from the ideal expansion ratio. The ideal expansion ratio is calculated from the pressure ratio at the design point of the nozzle. This is the ratio of external experienced pressure to the pressure entering the converging diverging nozzle.

III. Results and Discussion

This nozzle design shows an increase in thrust of 0.325% with relation to the conical nozzle designed by Cesaroni but the aerospike concept holds significantly more promise if used at higher pressure ratios as is shown by Fig. 1. This is especially the case with larger rockets as these would reach higher velocities and altitudes, thus experiencing a greater pressure change. This would allow greater use of the variable expansion ratio and greater efficacy of the aerospike with relation to a conventional conical or bell nozzle. While Fig. 1 is limited to displaying the conical nozzle present on the current motor it must be stated that the aerospike is able to make more efficient use of the base of the rocket for effective exhaust expansion [6]. This is true regardless of the rocket size and as such a similar graph could be drawn for most propulsion systems comparing a conventional nozzle to the corresponding aerospike. Thus the limitation on when aerospike nozzles are used becomes a question of nozzle mass. This is a complex topic that must be addressed for each propulsion system independently but in general it is postulated that the benefits offered by the aerospike nozzle concept grow as the propulsion system increases in size.

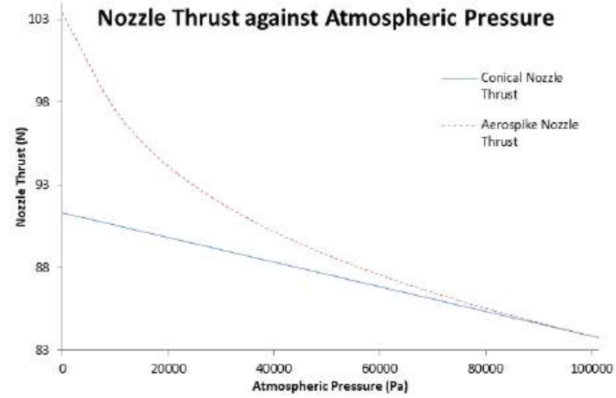

Fig. 1. A graph of nozzle thrust against atmospheric pressure showing the large improvements in thrust achievable by the aerospike at higher pressure ratios.

IV. Conclusions

An efficient nozzle has been designed using the Angelino approximation method [1] utilizing external flow conditions to describe an appropriate pressure ratio design point and back calculation of the motor internal gas properties. This has been shown to have an increase of thrust of 0.325% when compared to the conventional conical nozzle but shows greater promise if designed for higher pressure ratios, in particular when operating in very low pressure environments. It is therefore recommended that further research be done on integrating the aerospike concept into launch vehicles. The increased performance and efficiency this would bring could have drastic effects on the industry.

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FORAREX - Designing a Life-Support System for Microbiological Research aboard a Sounding Rocket

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***Abstract*— Goal of the FORAREX (FORAminifera Rocket EXperiment) project is the proof of concept for a rocket and space suitable life support system for foraminifera *Amphistegina lobifera* with integrated scientific sensors. *Amphistegina lobifera* is a unicellular marine protist with an external calcareous shell and diatoms as endosymbiotic algae. This first experiment demonstrates that the technical setup is feasible and works fully automated.**

This paper has been submitted in a similar version elsewhere.

***Keywords*— foraminifera, microgravity, cell physiology and motility, life-support-system, sounding rocket, REXUS/BEXUS programme, education**

I. Introduction

FORAREX (FORAminifera Rocket EXperiment) was developed by an interdisciplinary team of students from the University of Bremen. The technical goal of the FORAREX project is to proof the concept for a rocket and space suitable life support systems for the foraminifera *Amphistegina lobifera* with integrated scientific sensors. The used species *Amphistegina lobifera* is a unicellular marine protist with an external calcareous shell. In addition, it hosts diatoms as endosymbionts which photosynthesise. The experiment started three days before launch and continued for four weeks. During this period the sensors took pictures of the foraminifera and measured the water parameters. Moreover the water in the experiment setup was labelled to in order to distinguish the shell sections that have been grown before, during and after the rocket flight phase. The shell will be analysis by means of scanning electron microscopy. The biological goal of the experiment is to investigate the effect of microgravity on the motility and shell biomineralisation process of the foraminifera.

II. Material and Methods

A. Overview

The bases of the experiment design were the biological and the predefined REXUS/BEXUS manual requirements. First the basic needs of the foraminifera have to be covered: An observation chamber (FlowCell) with sea water to life in. The Temperature of the water should be around 20 °C but shall be in the range of 15 °C to 30 °C. The pressure in the FlowCell should be around 1 bar to avoid outgassing of the water. The water in the FlowCell shall be circulated to avoid high concentration of metabolic products. The artificial light shall support the photosynthesis of the endosymbionts. The diurnal cycle shall be 12 hours day and 12 hours night. To ensure these needs the foraminifera had to keep under laboratory conditions as long as possible. Because of this the containment with the foraminifera, water circle and integrated sensors has to be inserted via Late Access. As a next step, the scientific goals have to be fulfilled: To observe the motility and shape of the foraminifera a camera has to be integrated. To monitor the respiration and photosynthesis an oxygen sensor has to be included as well. Further the pH level has to be monitored. Because of the long experiment time, optical sensors are used. These sensors need temperature and pressure measurements to compensate their values. Moreover a biological filter was added in front of the area of the sensor spots to avoid a biological film, which could alter the measurements. To allow water manipulation a direct, leakage free access to the main water storage and the FlowCell has to be implemented. To increase the scientific output, the setup is doubled. Finally the REXUS/BEXUS requirements [1]: The experiment always has to be able to answer the service module. The experiment has to contain water absorbent material for twice the amount of water used. The experiment consists of two setups: The Late Access Module and the REXUS Module. The pressurised Late Access Module (LA Module) contains the two water circuits with the foraminifera, life support system (temperature, water circulation and light) and scientific sensors (camera, oxygen and pH) together with water absorption material.

B. Mechanic

The core of the LA Module is the stereolithographic printed FlowCell for the foraminifera. The observation chamber embedded inside holds the foraminifera in the camera field of view. To retain the picture sharpness the height of the inner observation chamber is minimized to 2 mm. This height depends on the insertion mechanism. To allow water flow but hold the foraminifera inside the observation chamber is partitioned by bars. The cameras shoot through a polycarbonate disc into the chamber. After watering and deflating the setup, the foraminifera are injected. This is done with a cannula (15 gauge; point style 5) through a triple septa and a moveable blocker into the observation chamber. The rotatable blocker prevents the foraminifera from moving into the injection canal, which is outside the area of camera observation. Rolling membranes keep the water pressure constant during injections or extractions. The water circuits also include the water

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reservoir with integrated oxygen and pH optodes including a thermal sensor and a deflation support. Peristaltic water pumps generate flow.

C. Thermal

Due to the biological part of the experiment, the temperature does not only have to fit during flight for measurements. The temperature has to fit at all times to ensure the survival of the organisms. The challenge of this design is to allow enough heat outflow to prevent overheating while the integrated experiment is in a warm environment (e.g. the laboratory or the heated launcher). At the same time, it has to keep enough heat for the time it lay in the snow after landing. To compensate the necessary thermal outflow, an active heater is added to the insulation.

D. Electronic

The controller of the experiment is a Raspberry Pi Compute Module 3. The two cameras are Raspberry Pi Cameras v2 (8 MP). The oxygen sensors in the two water cycles are Pyroscience Piccolo OEM. The combined pH and oxygen sensor in one of the water cycle is a prototype supplied by PreSens. For temperature measurements in the water, a PT100 is used. For air pressure measurements a MS580305BA01-00 is used.

E. Software

The Raspberry Pi Compute Module 3 run by Raspbian a Linux OS especially for Raspberry Pi Boards. It handles the data management and includes the basic drivers. The control program for the sensors and actuators is written in C++. It communicates via the REXUS Service Module with a ground control station for monitoring. The ground control station is written with QT.

F. Chemicals and foraminiferas

The foraminifera species *Amphistegina lobifera* was provided by the AG Kucera of the Marum, Bremen. The used ones are sized around 1.3 mm. The species hosts diatoms as endosymbionts. The standard artificial seawater for cultivation was Tropic Marin® CLASSIC SEA SALT which was modified by injected labels like strontium chloride-hexahydrate. The injections were always done in a laboratory.

G. Sounding rocket and flight

The REXUS 25 rocket was equipped with an "Improved Orion" motor. On board were five experiments (FLOMESS, HEDGEHOG, PR^3, FORAREX and GAME). The weight of the setup was 541 kg by 5927 mm length. The lift-off was on March 11^{th}, 2019 at 09:20 UTC. The altitude was at least 82.184 km with around two minutes of microgravity. The late access module was inserted after start of countdown at T-170 min. The functionality of the sensors was checked by uplink/downlink communication before lift-off.

III. Results

The injection of the foraminifera and the labels were successful. The Late Access was done on schedule.

The cameras worked nominal during flight as well as the other sensors. The only exception was the PyroScience oxygen sensor of water circle 0. After recovery we found the fiberglass cable was broken. The electronics worked nominal. The ground control station also worked nominal. During flight the sensors recorded a pressure decrease from 1000 mbar to around 530 mbar. During flight the temperature increase, the concentration of oxygen within the water decreased and the pH value increased slightly. After recovery the temperature was at 14.319 °C. During the week after launch a leakage of water was detected. All known weak points were additionally sealed with silicon. But the leakage continued. After disassembling it turned out the leakage was caused by broken pump tubing. This was in contrast to the conducted tests. Moreover while disassembling the foraminifera of FlowCell 0 did not stay in the dedicated area. This was in contrast to the conducted tests, too. It was found in the tube connected to the FlowCell. The inner parts of the setup were very clean without noticeable biofilm growth at disassembly. A ground control experiment was done after the flight campaign. In this the pump tubing broke again and one foraminifera slipped into the tube as happened during the flight experiment. Everything else worked nominally. Further vitality, shell and water analysis of both experiments will be published in a separate paper.

IV. Discussion and Conclusion

The broken fiberglass cable of water cycle 0 caused disturbances in the oxygen measurements. Luckily there was a second oxygen sensor (Presens) in this water cyrcle. So after repair it considered as a systematic failure. The pressure decrease during flight was still above the water boiling pressure point. The temperatures during and after launch were in accordance with survival of the organisms.

All in all this first experiment demonstrates that such a technical setup is possible and feasible. Off course the setup need further improvements for follow-on missions. For the all occurred problems solution possibilities with high potential are already in mind.

Acknowledgment

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Supporting STEM Education Through High Altitude Balloon Platform Development

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***Abstract*—Qualified engineers with good theoretical and hands-on experience are vital for a country's healthy space industry. However, if a country lacks of space and aerospace related higher education opportunities, developing a full university master or bachelor program requires high effort. Therefore smaller and local educational projects may play significant role in talent management and development.**

The UPRA Project (Universal Platform for Robotics and Aerospace) is a student project with an aim to develop a reliable, widely configurable, low maintenance, high altitude balloon platform for university research groups. The project not only offers flight opportunities but also provides hands-on experience on platform development, payload integration and project management.

Students who join the project can learn the main principles of space- and near-spacecraft development. Working on different subsystems requires different skill-sets which students can improve with the help of experienced team members and mentors from the space industry. Since a spacecraft is a complex system, project members are needed to specialize in different fields of engineering and science. This is an opportunity for students to gain confidence and experience in their field of interest of their later professional career and also helps them to select the proper path of their academic progress.

UPRA Project also offers flight opportunities for third-party payloads which require wider project management skills than a typical development project. To maintain a reliable launch service flight-planning, logistics, legal paperwork and field work at the launch event have to be done. All these activities are performed and organized by team members which increase their skills in project planning, project management and account management.

Beside university students the project also aims for the younger generation to promote STEM fields and reach out for the next generation of engineers. This goal let the team cooperate with 'Kids University' an event of Budapest University of Technology and Economics and also with the Space Camp of the Hungarian Astronautical Society. These partnerships made it possible to the project to demonstrate balloon launches to more than 250 young students in the first quarter of 2019.

Unmanned aerial vehicles and high altitude balloons are great assets of space education as they provide hands on experience through exciting engineering tasks which could be the base of the professional career of any student that takes part in the project.

Keywords*—*high altitude balloon, higher education, system engineering, STEM education

I. Introduction

One of the most important aspects of the project's educational motives is its flexible project roles. The team members have the opportunity to define learning goals for the upcoming semester. This involves the usage of flexible project roles. Thus the participants have the chance to apply to different roles and responsibilities to each and every launch event if these roles align with their skill development plan.

Besides focusing on engineering students who take part in the platform development project it is important to open towards other fields of space exploration. Providing launch opportunity to third party payloads allows non-engineering students to join the exploration of space by working on experiments that can be launched to the stratosphere.

This paper covers how the different parts of this high altitude balloon project can interact with students, which skills can they improve by selecting the given task and also introduces how the development of each subsystem of the balloon platform can enhance the aerospace engineering knowledge of a participant.

II. UPRA Ballon Platform

The goal of the Universal Platform for Robotics and Aerospace (UPRA) Team of Simonyi Karoly College for Advanced Studies is to develop a configurable modular balloon platform for the aid of university research groups who are interested in sending payload to the stratosphere. The platform is designed and built completely by students and is able to fly small science payloads up to 30 kilometers altitude. The UPRA Team is planning to establish a launch service targeting university research groups to provide an affordable platform, launch, recovery and flight planning services for their research.

The platform provides a bidirectional radio communication, live position tracking, data collection and storage and science data transmission. The platform is equipped with redundant tracking and communication system and an independent landing tracker to narrow the landing area.

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The platform is highly configurable and requires low maintenance between flights which makes it suitable for frequent or tight schedule stratospheric missions. A standardized payload gondola is under development to lower the expenses and the payload-platform integration time.

Fig. 1 shows the exploded CAD illustration of the platform-avionics module.

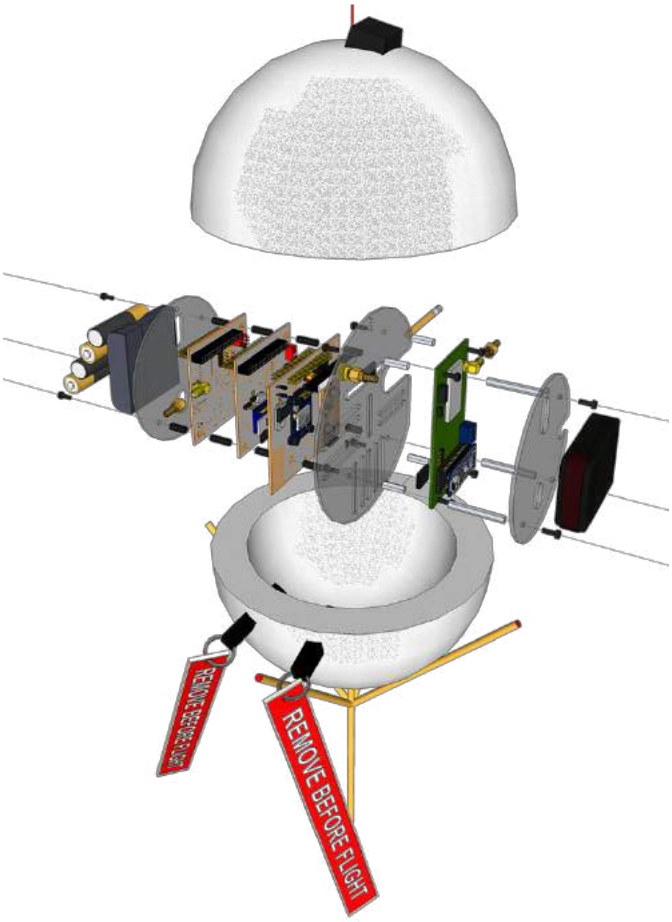

Fig. 1. UPRA Platform exploded view [4]

III. PROJECT MANAGEMENT

The summer semester held two big opportunities for the students to take up in project manager role. We launched our Fly With Us campaign with the objective to support third-party organizations to develop payloads for stratospheric flights with our platform system and our launch and recovery service.

In July we took part in the Space Camp of the Hungarian Astronautical Society in the city of Sátoraljaújhely, Hungary. This annual camp is for high school students with interest in space and space related activities. Campers can take part in workshops, short seminars and trips to nearby museums. Every year guest presenters give some interesting lectures and organize hands-on activities that bring the campers closer to space exploration. In the Space Camp our Fly With Us programme had its first proof-of-concept flight. We had external payload, as requested by the organizers. The payload contained the official flag of Sátoraljaújhely, the host town of the event and presents to the participants. Since part of the payload was prepared as a camp activity the previous day, we had to present a quick and safe payload integration.

After the Space Camp we have been contacted by one of Hungary's most popular radio stations (Radio 1) to plan and conduct a stratospheric balloon flight for them (Fig. 2). Their request was to develop a payload, that represents one of Hungary's national symbols. This provided an extremely useful learning opportunity to the project manager of the launch, since the flight development had a challenging payload (lángos, a national food of Hungary), a tight development schedule and the flight was live-streamed and broadcasted to more than 100.000 people nationwide.

Fig. 2. Launch at Radio 1 headquarters as part of our Fly With Us programme [1]

IV. ON-BOARD COMPUTER (OBC)

The On-Board Computer (OBC) is responsible for on-board data handling, collecting housekeeping data from the subsystems and controls the payload if necessary. Students working on the OBC become familiar with the development of microcontroller based real-time embedded systems. Gaining experience in developing fault-tolerant software, handling digital electronics and different communication protocols are valuable asset in the aerospace industry. Working with the development team does not only provide learning opportunity to design embedded circuitry but also tutor students in the assembly, integration and validation (AIV) process.

Even though the balloon platform is built with commercial off the shelf (COTS) components it needs to operate in extreme space-like environment. This requires the students to learn how to test and validate both the hardware and software modules. To ensure the reliability of the system validational tests are ran after every new modification on either the hardware or the software. Prior flight as part of the pre-flight preparation, all embedded subsystems are tested and the internal bus communication is also validated.

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The current flight model is based on an Arduino compatible Atmega328p microntroller which combined with the Arduino IDE provides relatively easy development of the OBC. This design makes possible to use off the shelf Arduino boards during early development stage as breadboard models. Since the Arduino environment is easy to use it provides a fast learning curve for students in the beginning of their academic life.

V. TELECOMMUNICATION (COM)

The hardest and most vital part of a balloon mission is providing reliable 'telemetry and telecommand' (TC/TM) function. The UPRA platform provides two way radio communication to transmit telemetry and housekeeping to the ground (telemetry) and to receive control commands from the operators (telecommand). Students joining the telecommunication subsystem development team can learn the basics of radio communication and the design principals of high-frequency circuits.

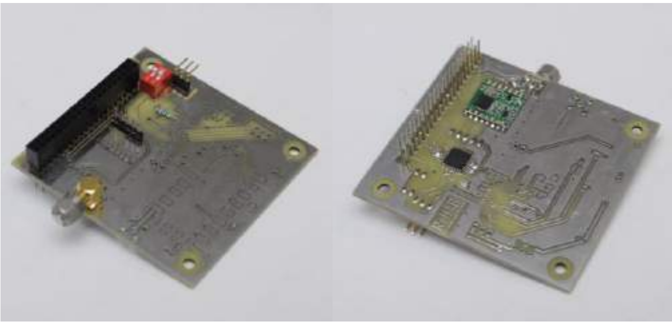

Fig. 3. UHF Communication subsystem with HOPE RF transceiver module

The current flying version of the communication subsystem is using an off-the shelf HOPE RF transceiver module (Fig. 3) which has limited efficiency. Students taking part in the further development of the COM can learn how to improve radio frequency (RF) circuits, designing better filters and amplifiers and fine tuning high-frequency hardware elements. The goal is to change the factory assembled HOPE RF modules to a more stable custom made RF circuit developed by the UPRA Team.

VI. GROUND SEGMENT

Alongside the on-board communication system, the ground segment is also under development. Currently the ground station transceiver hardware is the same as used on board the balloon platform. However it is equipped with a different firmware. This makes the ground connection highly compatible with the flying segment but provides very low configurability. As a preparation for later missions the upgrade process of the ground station is based on software defined radio (SDR) solutions. As part of the ground station development students will install an automated antenna rotator on the top of Schönherz Dormitory which is a nineteen story height building and the headquarters of our operations.

The ground station also needs a mission control software. Students interested in computer science can join the ground software development. The mission control software is a web based application using Python as backend and JavaScript as frontend. The goal is to develop a modular application which can be easily configured for different missions and different platforms. The current version of the software has already been supported several balloon flights and has been used to control a mobile rover at competitions.

Further development on the ground station software is to integrate with a live balloon trajectory predictor using live meteorological data thus providing real-time predictions on the landing site. Another goal is to use multiple radio stations simultaneously which could provide large coverage on balloon flights and can be the foundation of an advanced satellite tracking system.

VII. POWER SUPPLY AND DISTRIBUTION (EPS)

The basic of all electrical equipment is analog circuitry. Students working on the Power Supply and Distribution subsystem can master their skills in analog electrical design and testing. This sub-system is a crucial part of any space- or near-spacecraft. Precise calculations, simulations and analysis should be performed in early development phase. However besides working on paper, students can gain experience in manufacturing, hand soldering, testing and fine tuning analog circuitry during the assembly, integration and verification (AIV) process.

Students interested in analog electronics can also work with different sensors and signal conditioning. On-board a spacecraft various analog sensors are used, usually connected to an analog to digital converter (ADC). Students working on sensor signal conditioning can learn how to amplify, filter or trace the given signal in longer distance. With these skills team members can aid the circuit design and development in any subsystem containing analog circuitry.

The Power Supply and Distribution sub-system and analog signal conditioning are the backbone of every space- and near-spacecraft. Students possessing knowledge in analog circuit design and experience in analog AIV will have advantage building their carrier in space industry.

VIII. STRUCTURE AND INSULATION

Mechanical structure is important to fly experiments to the stratosphere. Parts should withstand vibration, extreme temperature changes and mechanical impact. The -60°C temperature in the stratosphere can be dangerous to the on-board electronics. COTS components used in the flight computer usually graded to -40°C as minimum operating temperature. To provide reliable operation sufficient insulation needs to be applied around the electronic subsystems.

Designing the mechanical structure and insulation can help students to gain experience in Computer Aided Design (CAD), set up and run thermal and mechanical simulations using the CAD models of the payload train and learn the basics of production and pre-production activities. Our workshop is equipped with a 3D printing and a CNC milling facility which can provide hands-on experience in the production of mechanical elements. Our headquarters also has a small thermal cooling chamber which could provide -16°C

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temperature. The cooling chamber can be used for preliminary testing and training workshops for students interested in testing and validation.

Since the launch of third party payloads started, a new challenge appeared in structure and insulation management. Equipment provided by customers requires a payload gondola. Currently the development of a general payload gondola is in progress which could provide standardized space for science payload on board of the UPRA platform. While most of the demands could fulfill with the standardized gondola there are payloads which requires custom made insulation and support structure (Fig. 4). The mechanical team should be able to design, manufacture and test these structural elements in a short deadline. This activity could be aided with the aforementioned 3D printer and advanced rapid prototyping techniques.

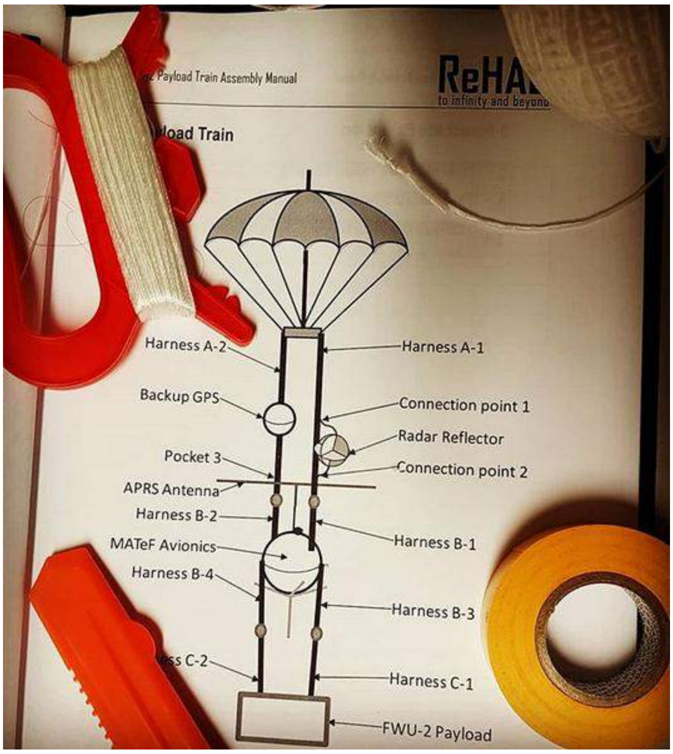

Fig. 4. AIV plan for the payload train with custom payload gondola

IX. BACKUP

In space engineering fault-tolerant hardware must be developed due to the harsh environment and lack of maintainability. Reliability can be achieved through the validation process (Fig. 5) but testing is not always enough. In a spacecraft crucial subsystems usually have backups in a form of a hot- or cold redundant pair. The key objective during a high altitude balloon flight is to recover the payload after landing. The UPRA platform is designed with several backup tracking capabilities to ensure the reliability of the recovery process. Besides the main GPS – which is connected to the On-Board Computer, - two independent GSM based trackers are part of the payload train. They are used to narrow the area of the landing site and act as a backup if the main on-board electronics fails.

The Telecommunication subsystem is also doubled. The flight computer uses the main GPS data to generate telemetry messages which then transmitted to the ground station via the main radio transceiver and as its hot redundant backup pair. The backup transmitter is only providing position data, but the message format used in the downlink does not requires a dedicated ground station, it could be decoded by automated HAM radio stations around the world.

All students work on this project have to learn the importance of fault-tolerant design and development to build reliable flight hardware. Using fault-analysis, verification and validation through the development process or gaining experience in redundant hardware design would give the students a point of view which can be advantageous in pursuing their space career.

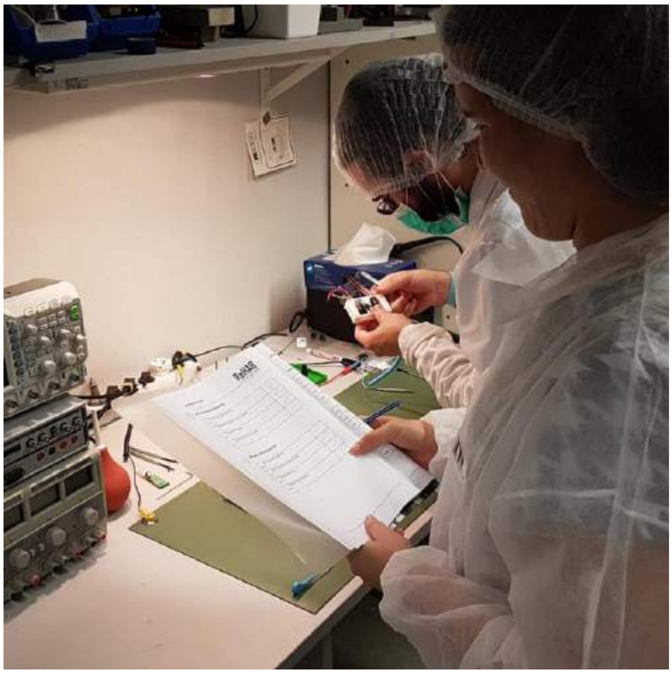

Fig. 5. Working on flying hardwer in 'grey' lab area to prevent contamination and ensure high quailty

X. FLIGHT MANAGEMENT

In the case of a high altitude balloon without active control planning a precise flight path is not possible. Flight planning usually relies on predictions calculated by the physical properties of the payload train and meteorological data. To eliminate dangerous situations, students involved in flight planning activities should learn how to analyze meteorological data, calculate and use payload train parameters and update predictions using already available applications or develop new ones. Flight planning also includes the scheduling of the flight, communication with authorities, organize the launch and recovery team. During the flight the launch and recovery teams are supervised from the mission control and reliy on the flight plan.

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Launch events can be followed by civilian audience at the launch location aided with crowd control (Fig. 6). After the launch team secured the area they start the preparation of the launch equipment and the payload. The complete launch process is controlled by the launch director who follows a checklist that contains instruction on balloon inflation, platform and payload start up and GO-NOGO conditions. The launch director is in live contact with the flight director and ground station personnel to gather information on current mission status and report any malfunction during the launch process.

The recovery is organized in advance using the flight prediction data. The recovery team departs after launch and heads to the predicted landing area while maintaining continuous communication with the mission control and with the balloon. During the balloon retrieval the route of the recovery team regularly updated using newest available predictions and live telemetry data. After the successful recovery of the returning payload train it is the responsibility of the recovery team to properly shut down the flight system and ensure the safe transportation of the hardware.

Fig. 6. Public balloon launch as part of Budapest Space Week with the audience of 'Kids University'

Launch and recovery team members can gain field experience during their activity. Being part of a field team needs great problem solving skills, proactive behavior and teamwork. These skills are important part in many fields of space engineering and can be beneficial for students seeking their carrier in space industry.

XI. Summary

Academic studies can be aided with projects providing hands-on experience to deepen the knowledge and further the horizon of students in their selected field. Students interested in space can have an opportunity to start their path by joining a high altitude balloon project. Working on near space equipment would help them gain the skillset needed for the space industry.

Since the beginning of the UPRA balloon project more than thirty BSc., ten MSc. and two PhD. students took part in the development. Most of them were studying electrical engineering and computer science. During the project timeline two thesis works have been accepted by the university. As the indicator of the project success we can proudly say that five of our alumni members have secured work opportunities in the space sector.

Our experience is that students who participated in the project had positive effects later on their professional carrier. The knowledge they gained during their time working with high altitude balloons is beneficial in many industries including fields of automotive, medical or aerospace engineering.

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Development of a solid rocket motor utilizing an ammonium nitrate based propellant

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Abstract

This project aims to design and build a fully functional solid rocket motor using an aluminum and ammonium nitrate-based propellant. The purpose of this motor is to power the flight of a stratospheric sounding rocket – Bondar –, developed for peaceful applications by the Cosmic Research Association. The design of the new motor begins by examining previous research performed by amateur rocketry experts like H. Olthof [1], R. Nakka [2], and D. Clouder [2]. To mitigate the legal and safety risks associated with the tenancy and handling of the substances needed for the motor, the project is declared as a university experiment and supervised by Universitat Politècnica de Catalunya. Cosmic Research has also reached an agreement with Lleida-Alguaire Airport, where static tests take place. The design of a fully functional motor is expected to be completed before Autumn of 2019.

Keywords: rocket; motor; Cosmic Research;

I. Introduction

Cosmic Research is a student association from Universitat Politècnica de Catalunya (UPC) focused on experimental rocketry. It is formed by a multidisciplinary team of engineering students who are currently working on Bondar, a sounding rocket equipped with the most powerful solid rocket motor ever built by European students.

II. PROPELLANT DESIGN

The new propellant chemical formulation needed to fulfill the following mission requirements:

- Avoid highly energetic and sensitive components to reduce the risks of detonation or sudden ignition.
- Possess a specific impulse greater than 200 s.
- Be produced at a low cost with high availability.
- Consist of non-hazardous and environmentally friendly components and reaction products.

Careful research and study on several successful ammonium nitrate (AN) propellant formulas developed by amateur rocketeers H. Olthof [1] and R. Nakka [2] was performed at the start of the Bondar mission. This revealed AN to be a promising oxidizer for the development of a "student-friendly" propellant. It offers high specific impulse values at a low cost with good availability, despite having some drawbacks regarding its chemical properties. Aluminum was also added to the composition. The selection of an optimal binder became a challenge that was overcome through multiple tests, including some molding, mechanical and ignition tests of small samples with different binders (resins, silicones and synthetic rubbers). These tests showed that polychloroprene rubber was a very good solution for the final formula. This decision implied using high-pressure compressing for the grain production in order to ensure a good propellant density.

Theoretical performance using *Propep*, a Propellant Evaluation software widely used in amateur rocketry, showed a Theoretical Specific Impulse of 242 s.

III. GRAIN PRODUCTION

A typical BATES propellant configuration was discarded from the beginning due to the expected high temperatures and constant pressure in the chamber. These conditions were desirable for the motor operation; thus, the propulsion team developed a mold that was suitable for high pressure compressing, enabling the production of relatively long grains with complex inner core geometries. These help to obtain an almost constant thrust and pressure profiles.

With the first prototype of the mold, it was possible to manufacture 150 mm long grains with an outer diameter (OD) of 65 mm and a circular inner core. After demolding, the grains where bonded together using the same binder over the inhibitor layer, to achieve a fully monolithic behavior. With the final design of the mold, it was possible to obtain 200 mm long grains of 160 mm OD with a star-shaped inner core, reaching values between 90-95 % of the theoretical grain density (5 kg/grain):

Figure 1. First demolding of a 5 Kg star-shaped propellant grain on August 12, 2019.

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IV. TEST FACILITIES

Propellant manufacture tasks and static tests demanded adequate facilities to perform these operations safely.

After exploring several options, Cosmic Research got in touch with Lleida-Alguaire's Airport Authorities, who agreed to sponsor the project. They offered Cosmic Research access to a 4700 m^2 paved surface (previously used for firefighter training) for the tests and manufacture of the propellant, as well as some safety advice.

V. TEST SETUP

The characterisation of the propellant formula was carried out using a Ballistic Evaluation Motor called Nebula-I (N-I, honouring the dense fog at Alguaire's airport during autumn seasons). The motor was designed to withstand unexpectedly high operating pressures, with 2 failure modes to avoid an explosion of the casing in case of a malfunction.

A replaceable graphite insert was used in the nozzle throat, allowing an easy modification of the throat diameter or even a complete replacement if damaged during the test campaign. This decision followed economic criteria.

The motor used a through-bulkhead initiator, developed by Cosmic Research and inspired by webpage publications of the Swiss Propulsion Laboratory [5]. It consisted of a little composite motor, with an easier to ignite formula of Potassium Nitrate + Epoxy. This mixture is ignited electrically, using a nichrome wire coated with a high temperature compound.

Figure 2. Through bulkhead initiator, showing the 4-nozzle configuration.

Threads were used for the bulkhead and nozzle holder to simplify assembly and disassembly. Sealing was achieved using aramid fibbers gaskets with an inox matrix coated with NBR elastomer (Provided by Epidor Technical Distribution).

VI. TEST STAND

For the validation of the setup, a heavy-duty test stand was designed and built by Cosmic Research in January 2019. The structure was designed to fit a wide range of motors (making minor changes) and withstand up to 20 kN of thrust.

The objective was to measure thrust and chamber pressure. A Honeywell MLH100BSB10A pressure transducer was used, as well as a 300 Kg load cell provided by Sensocar (Model S2-A). The outer chamber temperature was also measured using 3 type-K thermocouples.

Cosmic Research developed its own electronics to read, process and store data obtained from the sensors. Calibration was possible thanks to Sensocar and CCTC UPC (Heat and Mass Transfer Technological Centre).

VII. TEST RESULTS AND FURTHER DEVELOPMENT

A total of 7 N-I "less than perfect" successful motor tests were performed between February and May 2019. Solid data and valuable experience were obtained from the test campaign.

Performance data	
N-I propellant capacity	1,8 Kg
Propellant density achieved	1726 Kg/m^3
Max. Thrust delivered	1350 N
Average Total Impulse	3610 Ns
Average Specific Impulse	197 s
Burn rate coefficient "a"	2,43 mm/s/MPa^n
Pressure exponent "n"	0,43

Figure 3. N-I static test view. 02/03/2019.

Cosmic Research expects to design, build and test a solid rocket motor with a Total Impulse of 50 kNs, using the propellant formulation discussed in this document, during Autumn 2019.

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TRACZ - Testing Robotic Applications for Catching in Zero-g as the first step to research jamming phenomenon in the non-Earth conditions

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TRACZ - Testing Robotic Applications for Catching in Zero-g is a fully autonomous mechatronic experiment, launched on March 19, 2019, on board the REXUS rocket, during the 26th Campaign of the REXUS/BEXUS Programme. The main goal of the experiment was to investigate the jamming phenomenon in the space environment (microgravity and vacuum) as well as to construct a version of industry device known as jamming gripper, capable of operating in conditions where negative pressure (physical basis of operation in Earth-like conditions) cannot be obtained due to the presence of only a residual atmosphere. The structure was designed as 1-DOF manipulator, whose effector is an elastic membrane that stimulates jamming of ground coffee particles inside. During the suborbital flight, a series of catches were performed on a single object and the force with which the object is held was measured. The results were compared with an on-ground experiment.

Keywords: jamming phenomenon, gripper, rocket experiment, rocket payload, catching space objects, REXUS/BEXUS Programme

I. The jamming phenomenon

A jamming phenomenon, described as transition of grainy substances to solid-state under specific conditions is still a relatively unexplored issue. Theorems that classify the jamming phenomenon as a new example of a phase transition generate a need for a better description, modelling and definition of conditions of its occurrence. The jammed solid can be fluidized under the influence of temperature, vibration or mechanical stress. The generality of the jamming transition led to the proposal of a unifying description, based on a jamming phase diagram [1] (Fig. 1).

II. Motivation

Grasping different objects by robots in space conditions is in many cases neither effective nor convenient. Lack of general-purpose device which can grab differently shaped and sized elements made from various materials is one of many issues in space missions. A classical approach towards gripping objects by human-like rigid effector requires sophisticated trajectory planning algorithms, numerous sensors, and complicated mechanical design. Another approach is to use soft, elastic materials manipulated by pressure to adjust to an irregular-shaped object and catch it. Soft grippers are less complicated in construction and use, furthermore, they seem to be more all-embracing.

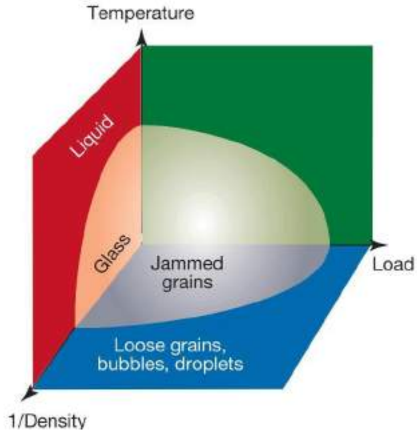

Fig. 1. Jamming phase diagram [1]

III. Gripper structure

The inspiration to create an unconventional tool came from new trends in the manufacturing industry. The Empire Robotics company has commercialized jamming-based robotic gripping technology in a product called VERSABAL[2]. This type of gripper is based on the jamming transition in granular systems. Pressurized membrane (e.g. neoprene in latex form) filled with granular medium (e.g. ground coffee) is adjusting to object, then depressurization of the membrane is performed

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and granular medium (and therefore also the object) gets jammed - the object can be manipulated (Fig.2).

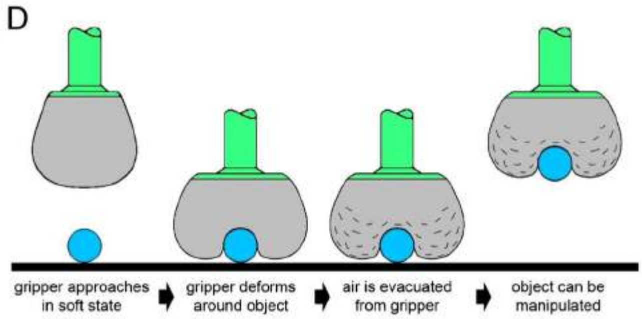

Fig. 2. Universal gripper based on the jamming of granular material [3]

There is no prior documented case of testing such technology in space conditions (microgravity and vacuum). Industrial jamming grippers might work with negative (down to -0,85 bar) and positive (up to 6,2 bar) pressures [4] to increase gripping forces. It is not possible to mimic this approach in a vacuum. It was also determined that behaviour of granulate in zero-g is unknown and may have a significant impact on the operation of the gripper. Moreover, in zero-g, minimal grasping forces needed to effectively manipulate the objects are significantly lower. Therefore suborbital flight under the REXUS/BEXUS programme was chosen as a test method as it offers exposure to both microgravity and vacuum for substantial amount of time, allowing to perform several, statistically significant, gripping procedures.

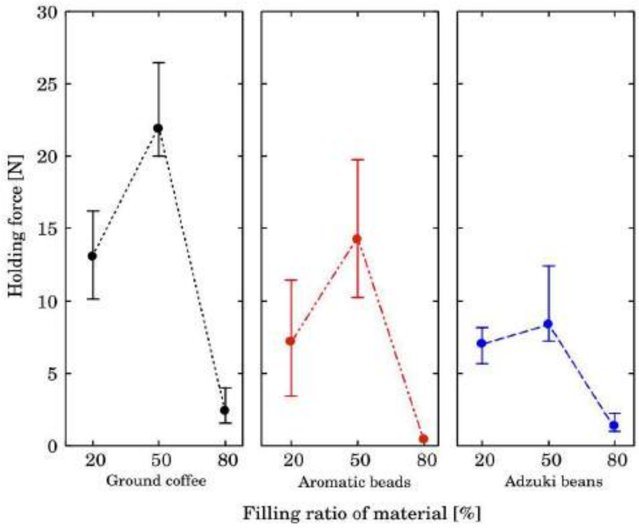

Fig. 3. Relationship between filling ratio and holding force of the gripper [5]

As commercial off-the-shelf jamming grippers are not adapted to space conditions, it was decided to design and build the effector from scratch. Based on the previous research, ground coffee was selected as the granulate (Fig. 3) [5]. For the membrane material two-component silicone was selected and its shape was formed in the casting process using various forms. Initial idea assumed oval gripper shape (offering greatest versatility), however, after many tests on Earth, it was concluded that oval membrane, lacking negative pressure, could not generate sufficient jamming to prevent the membrane from returning to its equilibrium position (oval shape), pushing out the object. Due to these issues, it was decided to change the shape of the membrane to the one shown in the photo of one of the prototypes (Fig.4).

Pressure control system consisted of two pressure regulators and two normally closed solenoid valves. Compressed air (reduced to around 60kPa with pressure regulators) was supplied from the tank to make grains loose in inflation phase. For air evacuation phase, outlet valve was opened to remove air from the membrane due to a natural pressure equalization (as the differential pressure is basis of operation, this method works in both a vacuum and an Earth's atmosphere). Membrane and pneumatic system were tightly connected with fastening and sealing elements printed from epoxy resin with SLA printing technology.

Fig. 4. End effector in two states (prototype)

IV. DATA ANALYSIS PLAN

The data gathered during the experiment was used to evaluate the utility of using the jamming gripper to grasp objects in the outer space. This utility was defined in the

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following manner. Firstly, the gripper should be able to catch the object. It is determined by a success rate in percentage over all the possible trials. Secondly The pushing force *Fp* should be as low as possible to not push back the object being grabbed and from the other hand, the holding force *Fh* (Fig. 5) should be enough to move the object.

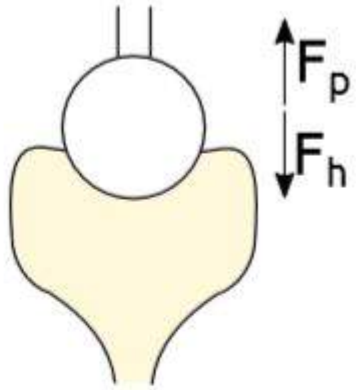

Fig. 5. A sketch of experiment setup

The experiment setup consisted of a set of sensors that allowed measuring all necessary parameters as the pushing force *Fp*, the holding force *Fh* and environmental conditions. The most important was the piezoelectric load cell to which the gripped sample was attached. This sensor allowed to measure the pushing and holding force. The second one, a differential pressure sensor measured the overpressure inside the membrane.

IV. Results and discussion

The main purpose of the experiment was to perform several grips with different pushing force *Fp* and observe the holding force *Fh*. It was decided to approach the sample with two different pushing forces of 40N and 50N. The results from the Earth experiment are shown in figure 6. As presented in table 1, the average holding force in case of 40N pushing force is 11.55N with standard deviation of 0.29N, and in case of 50N pushing force, it is 12.33N with standard deviation of 0.17N. The effector achieved 100% success rate on Earth.

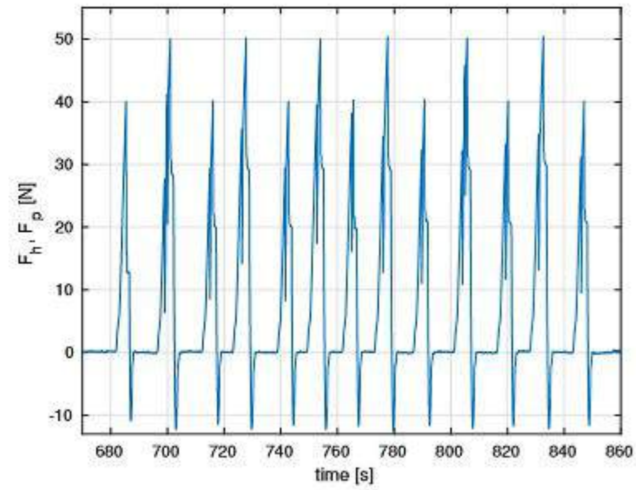

Fig. 6. Holding force Fh and pushing force Fp in time during Earth experiment

Table I holding forces Fh for given push force Fp during Earth experiment

F_p [N]	F_{h1} [N]	F_{h2} [N]	F_{h3} [N]	F_{h4} [N]	F_{h5} [N]	F_{h6} [N]	F_{h7} [N]
40	10.94	11.48	11.68	11.77	11.70	11.73	11.59
50	12.15	12.27	12.31	12.51	12.06	12.07	–

F_p [N]	Mean [N]	Std [N]
40	11.55	0.29
50	12.33	0.17

The results from rocket experiment are shown in figure 7. As presented in table 2 the average holding force in case of 40N pushing force is 10.58N with standard deviation of 0.19N, and in case of 50N pushing force is 11.55N with standard deviation of 0.23N. Also during the rocket experiment, the effector achieved 100% success rate.

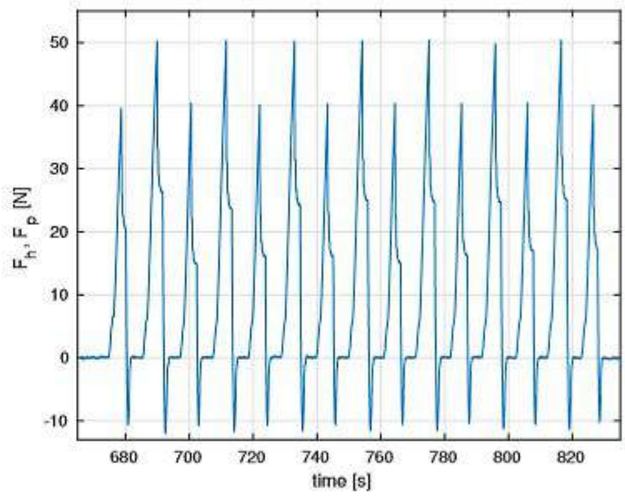

Fig. 7. Holding force Fh and pushing force Fp in time during Space experiment

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TABLE 2 HOLDING FORCES Fh FOR GIVEN PUSH FORCE Fp DURING SPACE EXPERIMENT

F_p [N]	F_{h1} [N]	F_{h2} [N]	F_{h3} [N]	F_{h4} [N]	F_{h5} [N]	F_{h6} [N]	F_{h7} [N]	F_{h8} [N]
40	10.68	10.81	10.72	10.57	10.60	10.50	10.56	10.17
50	11.91	11.65	11.67	11.60	11.50	11.27	11.25	–

F_p [N]	Mean [N]	Std [N]
40	10.58	0.19
50	11.55	0.23

To generate around 10N of holding force, the gripper has to push the sample with the force around 50N. The high pushing force can cause the object to be pushed away to the outer space. However, the series of experiments on Earth and in space show that the proposed gripper achieves similar performance in both environments, regardless of atmospheric pressure and gravity. However more experiments with different samples are needed to confirm it. Other effector shapes can also be explored, however, authors believe that another interesting (and perhaps more promising) idea is to extend soft gripper capabilities with use of smart materials, e.g. ferromagnetic material instead of jamming material to achieve the same gripping mechanism and to eliminate the aforementioned disadvantages of the jamming gripper.

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Studying Cell Physiology and Motility under Microgravitational Influence – Results of the FORAREX Mission on REXUS 25

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***Abstract*— The student project "FORAminifera Rocket EXperiment" (FORAREX) was developed and conducted within the student educational programme REXUS/BEXUS. Focus of this investigation was the cellular response of foraminifera to microgravity and the exceptional physical stress during rocket launch, e.g., vibration and acceleration. Further the launch impact on the shell building capacity of foraminifera was examined. For cultivating purposes, a life-support-system with a flow cell as observation chamber was built. Monitoring vitality and calcification was conducted with sensors measuring pH, oxygen and temperature of the sea water. FORAREX launched in March 2019 on the sounding rocket REXUS 25 on a nominal flight.**

This paper has been submitted in a similar version elsewhere.

Keywords*— *Foraminifera, microgravity, cell physiology and motility, Gravitational Biology, life-support system, sounding rocket, REXUS/ BEXUS programme, International Space Station

I. INTRODUCTION

Foraminifera are mainly marine unicellular organisms which typically produce an external shell, which can have either one or multiple chambers. These shells are most commonly made of calcium carbonate ($CaCO_3$) or agglutinated sediment particles. Foraminifera are characterised by streaming granular ectoplasm through their aperture called granuloreticulopodia, hereinafter referred as pseudopodia. The latter consists of cytoskeleton structures representing a multi-functional cellular network serving various purposes such as locomotion, feeding, digestion, and chamber formation [1], [2], [3].

First studies on mice show that foraminiferal shells can be employed as material for drug delivery systems, which allows for a better control of drug release than conventional applications [4]. Another important application is the use of the shells in bone revitalisation already tested in mice [4], [5]. Biominerals derived from marine organisms are an interesting field of research for nano-scale chemical reactions. The calcium carbonate can be coupled with different substrates, possibly enabling improved or even new manufacturing and processing methods [6], [7], [8], [9], [10], [11].

Crystallisation of biomolecules is already known to be different under microgravity than on Earth. For example, albumin crystals formed on board of the International Space Station (ISS) were significantly larger and more regularly organised compared to the same crystals formed under Earth gravity conditions [12]. As calcareous foraminiferal shells are compounds of proteins and calcite, we expect the crystallisation in their shell biomineralisation process to be affected in a similar way under microgravity. The complete process is not yet fully understood and thus an interesting field of research. This opens up the creation of new biomaterials with possible applications in drug development, formulation, manufacturing and medicine.

As preceding investigation for a long-term experiment on board of the ISS, where we would like to investigate foraminiferal shell formation and cell physiology under extended microgravity influence, the FORAREX experiment was developed and conducted in the course of the REXUS/BEXUS programme - an opportunity for university students to carry out scientific and technological experiments on board of sounding rockets or stratosphere balloons. The programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Agency (SNSA). The Swedish share of the payload has been made available to students from other European countries through the collaboration with the European Space Agency (ESA). Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project. EuroLaunch, the cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles [13], [14].

Under the limited microgravity duration provided by the REXUS sounding rockets, we focused on testing the equipment and the motility of the foraminifera *Amphistegina lobifera* Larsen 1976 [15] during launch and flight in comparison to a control group.

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Since microgravity induces changes in cytoskeletal structures [16], it is interesting to investigate if the pseudopodia of the living cell would change under microgravity, as the shell of foraminifera is synthesised using the pseudopodia as a template. Additionally, the shell building capability and motility was investigated by optical means, scanning electron microscopy (SEM) and nanoscale secondary ion mass spectrometry (nanoSIMS) after 4 weeks post-flight cultivation. For improved shell analysis we labelled the shells with strontium isotopes. For this experiment, we designed and constructed a Late Access Module (LA Module) accommodating the closed-circuit life-support system with integrated LED-based illumination for real-time observations of foraminifera and tested it successfully under reduced gravity and sounding rocket mission conditions. Low-drift optical sensors continuously measured oxygen (O_2) and pH level. Water temperature and ambient pressure were measured with electronic sensors. Foraminifera were recorded with integrated and automated Raspberry Pi cameras.

II. Material and Methods

A. *Life-support system*

The designed life-support system consisted of two independent water circulation cycles. Each cycle system contained one flow cell to hold the organism, UV-lights for sterilisation, a water tank, a peristaltic pump, LEDs for photosynthetic active radiation (PAR), a camera and sensors for measuring oxygen concentration, temperature and pH level (Fig. 1). The system was controlled by a Raspberry Pi Compute Module 3.

A minicomputer read out the cameras (one for each chamber) and the sensor values O_2 and pH level for water cycle 0 (Exp0) and O_2 for water cycle 1 (Exp1). Further it read out temperature, air pressure and values of an inertial measurement unit (IMU). Moreover it controlled the actuators (pumps, heater, fan and LEDs (PAR and UVC)). Furthermore a real time clock for better time references and temperature sensors for active temperature regulation was integrated.

Each flow cell functioned as an observation chamber for one single foraminifer. Injection of the organism was done via a cannula through layers of septa at one side of the flow cell. This was necessary for injection of the foraminifera into the fully assembled LA Module shortly prior to lift-off (LO).

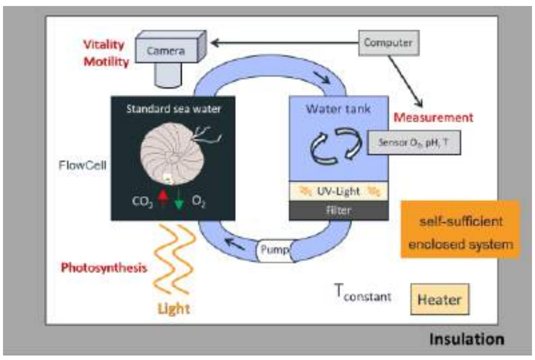

Fig. 1. Schematic diagram of one water cycle. Each water cycle is a self-sufficient enclosed system.

B. *Experimental set-up*

Foraminifera 1.3 mm in diameter were used. This ensured visibility of the organisms and their pseudopodia. The foraminifera were kept in artificial seawater (Tropic Marin® CLASSIC SEA SALT, according to Standard ASTM D1141-98) at 20 °C under a day-night cycle of 12 hours light and 12 hours darkness. The simulation of the diurnal rhythm was conducted with light according to the required photosynthetic light spectrum of the endosymbiotic algae (diatoms *Fragilaria shiloi* J. J. Lee, Reimer & McEnery 1980 [17] and *Nitzschia panduriformis* Gregory 1857 [18]). Food for the foraminifera was omitted in order to stimulate foraging movements of the cells.

Supplementation of the culture medium with strontium was necessary in order to distinguish the shell sections that have been grown before, during and after the rocket flight phase. A first chemical labeling with strontium chloride-hexahydrate ($SrCl_2*6H_2O$) was added to the sea water 6 days before launch. Strontium-86 carbonate isotope ($^{86}SrCO_3$) was added as a second label the day after flight.

The cells were inserted into the flow cell 2 days before rocket launch. The LEDs placed directly above the foraminifera supplied them with light for photosynthesis and illuminated them when a picture was taken by the cameras. Pictures were recorded every 2 seconds and sensor data were recorded every 5 seconds before, during and after flight.

After recovery, the experiment was run for additional 31 days at 20 °C in an incubator and then disassembled. Cells were evaluated for evidence of life in petri dishes with freshly added food. Shell integrity of the foraminifera was evaluated by means of light microscopy.

A ground control group was conducted in the same experiment procedure apart from the rocket launch and flight.

C. *Sounding rocket and flight*

The REXUS vehicle is a one-stage rocket, consisting of an improved Orion motor and the payload. This rocket gives approximately two minutes of microgravity conditions with a payload mass of up to ~95 kg, including the service and recovery systems [14]. REXUS 25 was launched on 11th of March, 2019 at 10:20:00 local time (LO UTC+1:00) with five student experiments (FLOMESS, HEDGEHOG, PR^3, FORAREX, GAME) on board from the European Space and Sounding Rocket Range (Esrange) near Kiruna, Sweden. The total weight of the sounding rocket setup was 541 kg at a size of 5.927 m.

The LA Module was prepared shortly before launch and was inserted into the rocket 2 hours 50 minutes before LO. The successful connection was checked via the uplink/downlink communication.

Rocket motor burnout was after T+26 s. At T+67 s (67 seconds after LO) yo-yo de-spin was set in shortly followed by the rocket motor ejection at T+70 s. Apogee was reached after T+124 s at a minimum altitude of 82.184 km. Parachutes were deployed at T+5 min 55 s and T+6 min 20 s and the rocket landed at T+13 min 41 s.

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III. RESULTS

As the launch was scheduled for early morning, the LA Module was prepared a day ahead and was completed in time. All the systems of the experiment operated as planned during the nominal flight.

Water temperature increased up to 31 °C – 34 °C during flight (Fig. 2, 3). Oxygen concentration in both water cycles dropped sharply a few minutes after LO (Fig. 4, 5). Pressure within the flight module dropped from 1,000 to under 600 hPa at LO (Fig. 7). Alkalinity spiked from pH 7.09 to pH 7.13 at LO, then stabilised at pH 7.11 during parachute breaking and landing (Fig. 6).

After a successful recovery, the LA Module was brought back to the laboratory to supply it with electricity for the post-flight data recording. Both water cycles showed an initiate temperature of 14 °C – 15 °C.

In-depth analysis of the post-flight data as well as the launch and microgravity impact on the shell biomineralisation will be published in separate papers.

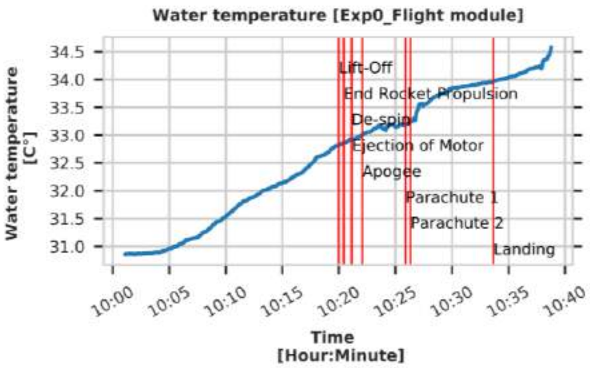

Fig. 2. Water temperature of Exp0. LO at 10:20:00 local time (UTC+1:00).

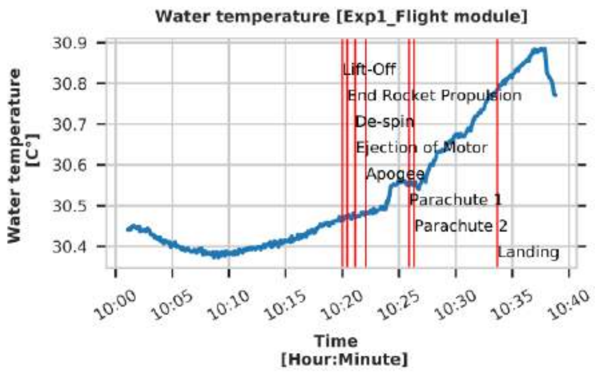

Fig. 3. Water temperature of Exp1. LO at 10:20:00 local time (UTC+1:00).

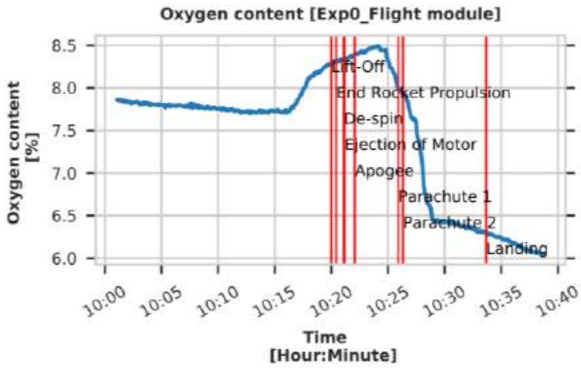

Fig. 4. Oxygen content of Exp0. LO at 10:20:00 local time (UTC+1:00).

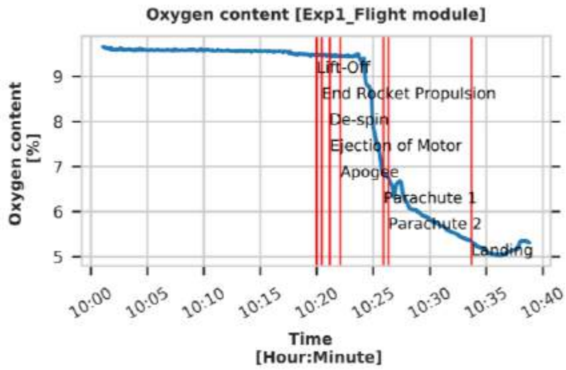

Fig. 5. Oxygen content of Exp1. LO at 10:20:00 local time (UTC+1:00).

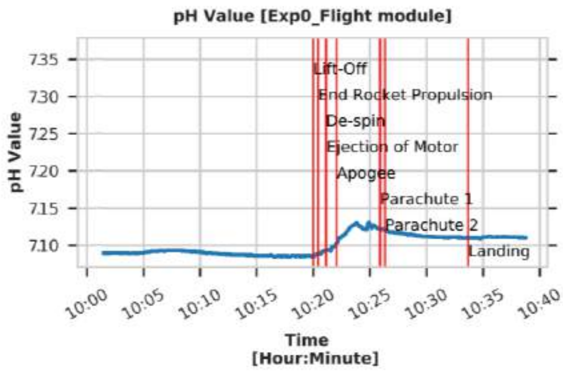

Fig. 6. pH Value of Exp1. LO at 10:20:00 local time (UTC+1:00).

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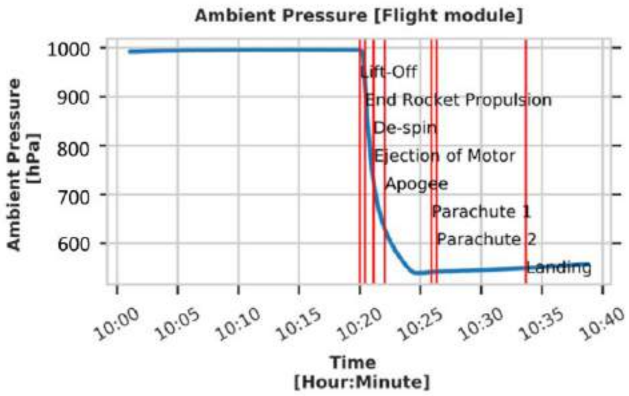

Fig. 7. Ambient pressure inside the LA module. LO at 10:20:00 local time (UTC+1:00).

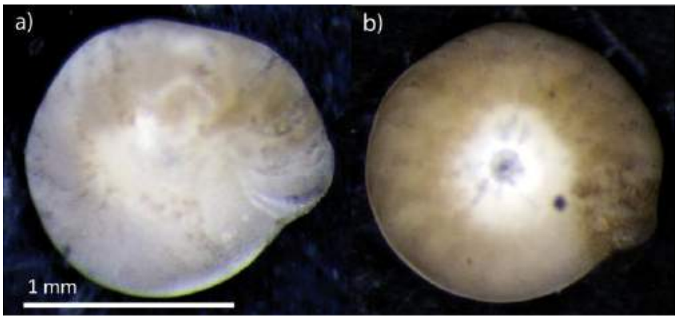

Fig. 8. Specimens of *Amphistegina lobifera* used in this experiment. Scale bar is 1 mm. a) Foraminifer in water cycle 0 (Exp0), b) foraminifer in water cycle 1 (Exp1).

IV. Discussion and Conclusions

Cameras and monitoring sensors worked within the limits of their specifications, allowing the observation of living foraminifera during rocket flight. The increased water temperature before flight derived from the heated environment (30 °C – 31 °C), especially applied by the ground operation crew for this mission to prevent freezing of the foraminifera, before the rocket was brought into launch position. The insulated LA Module kept the water temperature within range until landing.

The major drop in oxygen concentration in both water cycles is presumably due to the drop of the ambient pressure within the LA Module. This may have caused some outgassing of dissolved atmospheric gases (nitrogen, oxygen and carbon dioxide), as the solution of gases in water is pressure-dependent. Outgassing of carbon dioxide may be indicated by a slight shift in alkalinity shortly after lift-off. During parachute breaking and landing, the carbon dioxide redissolved in the water due to increasing ambient pressure and restored the original alkalinity by forming carbonic acid.

In summary, our life-support system and LA Module were suitable to observe living foraminifera during rocket flight.

Acknowledgment

We thank our supervisor Professor Dr. Michal Kucera and his working group from the Center for Marine Environmental Sciences (MARUM) of the University of Bremen for providing us with *Amphistegina lobifera* and helping us with their expertise. We also would like to thank the Electronics Workshop of the working group on Microsensors of the Max-Planck-Institute of Marine Microbiology and Professor Dr. Jelle Bijma and his working group on of Marine BioGeoScience of the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research for counselling interviews. To our consulting and material supporters from the aerospace sector Airbus, the German Research Center for Artificial Intelligence - Robotics Innovation Center (DFKI GmbH RIC Bremen) and the OHB Systems AG we would like to express our sincere thanks.

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We would like to offer our best thanks to Dr. Hans-Konrad Nettmann and Professor Dr. Karl-Heinz Blotevogel for scientific advice and logistic services. A big *thank you* goes to Timothy Sondej for helping with Python scripting and consulting in data analysis.

Finally, we seize this opportunity to extend our deepest thanks and appreciation for the REXUS/BEXUS programme and its supporting agencies, namely the German Aerospace Center (DLR), the Swedish National Space Agency (SNSA), Swedish Space Corporation (SSC), European Space Agency (ESA) and the ZARM Drop Tower Operations and Service Company for their outstanding support to make this project possible.

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ASTRE : a student-directed space association building a 2U Cubesat and an Open Source ground segment

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Abstract— **ASTRE is a student association created in Toulouse, France, to develop students' interest for space science and technology. The association is currently developing two different projects.**

Keywords— Education ; Cubesat ; SatNOGS; Student; Open Source; Gravimetry; Ground Station

I. ASTRE, A STUDENT ASSOCIATION FOR SPACE SCIENCE

The Students Space Association of Toulouse (ASTRE) is a student-directed and space-oriented association, supported by university teachers and staff members. Its main objective is to develop students' interest for space science and technology. This is reached by developing engineering projects and enabling students to participate in international and national workshops and conferences. Today, 25 students from four different engineering schools of Toulouse participate in ASTRE activities.

ASTRE vocation is to give to the maximum of Toulouse students the possibility to participate in projects linked to space technologies. Toulouse is the aerospace capital in France with several huge space companies. Yet, most of Toulouse engineering schools do not have space-oriented courses so the association is a unique opportunity for motivated students to learn more about this field. ASTRE students are encouraged to participate in space-related activities and to attend conferences about spatial news and spatial science and technology.

Students can find in ASTRE the support that they need to dare to discover the spatial field, which is often seen as complicated and inaccessible. The association members can also be provided with financial aids in order to participate in rewarding activities for their future.

In the last year, 30% of ASTRE members have participated in international workshops and conferences. Each time, back in France, participants share their experiences and new knowledge with the rest of the members. This sharing philosophy is the main axis of the association, making possible to reach the educational objectives and moving forward.

A part from participating in international events, ASTRE members are encouraged to participate in space-related events in Toulouse, France, where the association is based.

One membership condition is to be engaged in one of our long-term projects. We are currently working in two different projects and we are starting a third one in October 2019. All the projects developed by ASTRE are oriented towards education, innovation and Open Source.

II. TOLOSAT

Tolosat is a 2U CubeSat with a double mission developed in collaboration with Club CubeSat Supaero. The main objectives of the mission are to measure Earth gravity field variation from GNSS tracking and to send and receive telemetry via the IRIDIUM constellation.

There is a group of 38 students from five different universities working in TOLOSAT. Those students are organized in nine groups, one for each engineering field, and come from different engineering backgrounds. In each group, students from different studying levels work together and share their knowledges following ASTRE's work philosophy. TOLOSAT members are helped by experts when they need it but there any teacher is leading the project, as we want our CubeSat to be a spacecraft fully made by students.

Every year we have the pleasure to welcome new students in TOLOSAT team. New members have a training period with old members that have already worked in the project. Experienced members teach to the new ones the required concepts to follow the mission without starting from zero every year. This method ensures the continuity of the project even if the group changes every year.

The project started in January 2018; we ended phase A in June 2019 after a Preliminary Design Review and we are starting phase B in September 2019. The estimated launch date is 2022.

III. ASTRE'NOGS

ASTRENOGS team is building a UHF/VFH ground station to receive data from satellites. The project takes part of the

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European Nanostar program aiming to develop Open Source ground stations in Southwest Europe.

Currently, 5 students are working on this project since September with an engineer of ISAE-Supaero to help them. At the end, the station will be part of the SatNOGS open source network of ground stations. We are proud to contribute to this new kind of network, accessible to all the scientific community and using affordable tools and resources.

Plus, we are trying to create a detailed documentation on our project, to help and encourage future students to try the SatNOGS experience. ASTRENOGS project is totally in line with all the objectives of ASTRE and will be completed in December 2019.

IV. ASTRE PLANS FOR THE FUTURE

The association aims to develop new activities thanks to opportunities brought about by university teacher projects and students ideas. ASTRE has been created two years ago and meets a real success among Toulouse university students. Hence, the association is planning to continue growing during the following years.

ASTRE receives more and more application forms from students that are willing to work in one of our projects. However, we have now more applications than posts to offer to students. Thus, we are starting a new project this year, in order to reach more students from our city and give them the opportunity to take part in a space related project.

This new project is it going to be a sounding balloon mission and it will be finished by June 2020. We are also open to new proposals and ideas for new short or long-term projects.

V. SPONSORS AND NETWORK

We have lots of ambition and ideas of projects for our association. Unfortunately, we can't meet our goal without the help of people and companies. There is multiple ways to support us. All our sponsors are named at every event, it give them lot of exposure, especially among students

Another important point for ASTRE is the network. This year we want to develop even more ASTRE's network consisting of passionate of spatial. In a first time to share news among students. But also to develop a strong link with companies and professionals, especially within the area of Toulouse for technical advices and internship opportunities.

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Hands-on Space Activities at University of Nottingham

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Abstract— **The University of Nottingham launched the aerospace engineering programme in 2016. Four different courses are offered at both BEng and MEng levels with the BEng consisting of three taught years and MEng consisting of four.**

Space educational activities at University of Nottingham are mainly concentrated in offering hands-on experiences to students. Students at different levels, starting from the 2nd year, are involved in the design of space systems, mainly CubeSat standard compatible, that will be implemented and boarded in a small satellite.

The main educational project is dedicated to the design and analysis of the first space mission from University of Nottingham. The idea is to use a CubeSat platform and implement a payload of interests for students and researchers at University of Nottingham. At this phase several payloads are under evaluation. The students are supported by a board of staff members involved in different space activities from biomedical research in space to earth observation to the use and application of GNSS. Once identified the mission that will be carried out the student will be involved in all the mission phases, from the design to the launch and in orbit operation. A dedicated ground station will be installed at University of Nottingham in order to be able to track and receive satellites in UHF, VHF and S band.

In addition, to implement student experiences and have soon the opportunity to see the first system designed at University of Nottingham in space, several international cooperation have been made with European partners, such as University of Beira Interior and CEIIA in Portugal, and non-European partners such as, for example, University of Brasilia in Brazil. The goal of these cooperation is not only share knowledge and experiences between teams but also launch opportunities and future opportunities.

As part of the educational project the students are also involved in balloon projects, where the systems will be tested using High Altitude Balloon. Next balloon mission is planned to be launched in November 2019.

The paper gives an overview of all the most interesting space educational activities involving students at University of Nottingham giving particular attention also to the improvement that will be done in the existing facilities in order to have a more effective Space Systems Educational Laboratory.

Keywords—CubeSats, PocketQubeSats, High Altitude Baloon

I. Introduction

In 2016 the University of Nottingham (UoN) launched a new educational programme in aerospace engineering offering four different courses at both BEng and MEng levels.
The four courses offered are a BEng Aerospace Engineering, a BEng Aerospace Engineering including an Industrial Year, a MEng Aerospace Engineering and a MEng Aerospace Engineering including an Industrial Year. A MSc in Aerospace Technology is also part of the UoN offer.
The Aerospace course is a joint project between the Department of Mechanical, Materials and Manufacturing Engineering (M3) and the Department of Electronical Engineering.
All students follow a common programme of study for the first two years, studying material that provides a comprehensive core expertise in aerospace engineering and aircraft technology. In the last two years students have the opportunity to learn and discuss topics related to Space engineering.
The space educational program aims to involve university students in real space projects based on the analyses, design, tests and in orbit operations of space systems, in general, with particular attention to small satellites.
The main system used are High Altitude Balloon platforms, PocketQubeSats, CubeSats.
Similar hands-on activities are conducted overall the world and in Europe are strongly supported by European Space Agency **Errore. L'origine riferimento non è stata trovata.**].
The educational space hands-on program, open also to all M3 students, can be divided in three different phases:

1. Teaching activities
2. Extra curriculum activities
3. Long term projects

The paper will analyse separately the three different phases giving some example of the projects conducted in the last 2 years.
To offer a high-quality hands-on experience University of Nottingham is offering the use of different facilities that are shortly described in paragraph 5.

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II. TEACHING ACTIVITIES

The teaching activities section groups all the hands-on activities conducted as part of an existing module. Students get credits and marks accomplishing these activities.
Main characteristic of these activities is a systems approach including an integrating design, make and test project along with laboratory and workshop elements.

A. *Group Design and Make*

As part of the learning experience, students at M3 have to work as a team to accomplish a specific project in engineering. A specific module, “Group Design and Make”, thaught at the 3rd year, involves students in a real hands-on educational activity. The module intends to replicate the challenge and environment encountered when designing as part of a team in industry. Professors from overall the department act as customers requiring a specific product with well-defined technical requirements, a limited budget of 500 £, and a time-frame of one academic year.
The project is organized in order to have four major milestones during the year:

- The Requirements and Planning Review (RPR)
- The Preliminary Design Review (PDR)
- The Critical Design Review (CDR)
- Customer Acceptance (CA)

Normally the proposed projects concern area related to M3 research and teaching activity. Regarding Space, the proposed project is the design of a small satellite class PocketQubeSat and test it. In the academic year 2018-19, a team of 4 students designed a 2p PocketQubeSat called PunchSat PocketQubeSats were initially proposed by Prof. Bob Twiggs in 2009 with the aim to have a satellite standard smaller and cheaper than existing satellites, with dimensions so small that can fit in a pocket. First PocketQubeSats were launched in orbit in 2015 through UniSat-5 platform [1].

PunchSat project aim is to design and fabricate a PocketQube Engineering Model in accordance with the PocketQube Standards [2].The satellite mission is really simple: to capture one picture with a digital camera.

During the project the students designed the platform, selected the components, integrated the different subsystems, manufactured the structure and the solar panels, designed and tested the software. They used different software available at University such as Solidworks, Abaqus, MatLab and STK to conducted the design and analysis phases.

Due to the limited available budget (500£) and some safety rules constraints the system has not been tested in an High Altitude Balloon (HAB) as planned. In any case the satellite has been designed in order to be launched to a low-Earth orbit (LEO). The satellite CAD model and the internal systems are shown in Fig.1 and Fig.2 respectively.

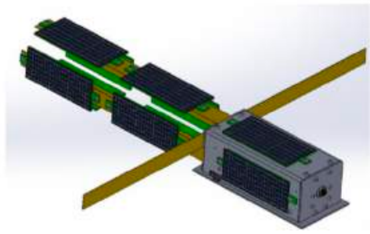

Fig. 1. PunchSat CAD Model (REF)

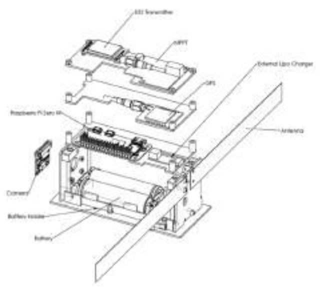

Fig. 2. PunchSat Internal systems

B. *Introduction to Space*

Since the last academic year M3 Aerospace students at the 3rd year can select the Introduction to Space module. The course is organized in two different main activities: theoretical lectures and practical lectures. During the practical lectures the students have the opportunity to learn the use of several software normally used by CubeSat developer team to design their mission. Cubesats are 10 cm cube (called 1U) invented by prof. Robert J. Twiggs and prof. Jordi Puig Suari. This satellite standard was invented with the main purpose of involve students in a real satellite mission. Recently the CubeSat became famous platform used by Space Agencies, Companies and Military to reach space and perform different kind of missions in different orbits, from LEO to Mars. One of the main characteristics of this platform is the relative low costs and flexibility [3].

During this module the practical hands on activity consist on performing an individual project or coursework. During the coursework the student has to think about a space mission that can be performed with a CubeSat (from 1U up to 3U) with a total budget of 2M of EUR and a timeframe of 2 years. If we consider the life cycle of space mission as defined in [4], the students have to conclude phase-0 (Mission analysis/needs identification) and phase-A (feasibility study) up to the PRR (preliminary requirements review) to satisfy the coursework requirements.

To support their activity the student will be have access to several software (3DExperience, Matlab, Abaqus) but also to official documentation coming from previous student satellite missions. In the next academic year students will have also the opportunity to use COTS platform such as the ESAT platform offered by TheiaSpace company to implement their hands-on space experience [5].

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C. *Spacecraft Systems and Design*

Spacecraft Systems and Design is a new module that will be introduced in the academic year 2019-20 for students attending the 4th year of the MEng Course. The course is specifically dedicated to the design of spacecraft systems and, due to its nature, it adopts a hands-on educational approach.

In particular the students enrolled in the module will select, together with the module convenor, a payload and integrate it in an existing platform. The platform is part of the BeeReady program from the company Open Cosmos and includes a mission simulator software (BeeApp) and a 3U CubeSat platform (BeeKit) [6].

In addition, the students will learn how to track and receive a satellite using the UoN UHF, VHF and S band ground station that will be installed before the end of 2019. In the near future, when the first UoN satellite will be put on orbit the students will have also the opportunity to learn how to operate a satellite.

D. *Individual Projects*

As part of all the M3 courses, the student has to work individually in a project and produce at the end a scientific paper (MEng) or a technical paper (BEng and MSc). One of the opportunities give to engineering students at UoN is the possibility to perform a hands-on project where they have to solve a real problem. Normally project proposals are coming from small companies, research teams inside and outside the university or even institutional organizations such national foreign companies. This will give them not only the opportunity to be involved in a real project but also the chance of discussing problems and find solutions with real "customers", researchers and experts coming from other institutions.

Last academic year for example students from MEng, BEng, and MSc where involved in projects concerning the design, analysis, prototype manufacturing and preliminary tests of space system of interests of different institutions as reported in table 1.

Some of the projects will be continued by future students and implemented in real satellite or mission. For example, the de-orbiting systems designed are going to be launched next year.

Other projects will be continued inside external companies by the students themselves and will become real products.

TABLE I. EXAMPLE OOF SOME MSC, MENG AND BENG HANDS-ON INDIVIDUAL PROJECTS PERFORMED IN 2019-20

Course	Individual project	
	Title	***Customer/ Required by Subhead***
MSc	De-orbiting System for CEiiA satellite	CEiiA (Spain)
MEng	De-orbiting Systtem for FloripaSat	FloripaSat team-University of Santa Caterina (Brazil)
MEng	Deploynent platform to release satellites from ISS	JAMSS/JAXA (Japan)
BEng	Design of a separation systems for PocketQubeSat	GAUSS (Italy)

III. EXTRA-CURRICULUM ACTVITIES

The general and strong interest among the students about space activities pushed them to be organized in team and associations with the common goal of performing additional hands-on experiences. Differently from the teaching activities described in paragraph II, in this case the students do not receive any credit or mark but get economical and technical support from M3 department. In some special case, as for example when the team are able to be involved in the ESA educational office program, parts of the work can be presented as individual project, but this is not always the case of this kind of activities. In this paragraph we will introduce only the most active student project called Ophelos and its results up to now

A. *Ophelos Project*

The OPHELOS (Orbital Platform Helping Experiment on Living Organisms in Space) project is being developed by a group of 4 students at the University of Nottingham and it focuses on developing an affordable CubeSat able to carry various biomedical payloads.

OPHELOS is split into different phases:

- *Initial testing phase – Phase 0*

The project is actually completing the initial phase or phase 0. The main goal of this step is to test a student-made scintillator and the thermal control system on a high-altitude balloon (HAB) with a mockup payload and a required power supply unit (PSU). The HAB launch was planned for June 2019 but postponed to October 2019 for some restriction related to the University safety rules. All the structural components have been manufactured by the students using existing facilities. Fig. 3 shows the 1U CubesSat structure with some subsystems before the integration.

- *First orbital test – Phase 1*

First orbital platform is planned to be a standard 1U CubeSat (100x100x113.5mm). OPHELOS-1 will be a platform mainly focusing on testing the main satellite subsystems The main payload is proposed to be the scintillation detector, consisting of 3 types of crystals: BiGeO, $CdWO_4$ and $PbWO_4$. A preliminar test of the thermal control system (TCS) will be conducted the biological sample at 37ºC ± 0.5ºC.

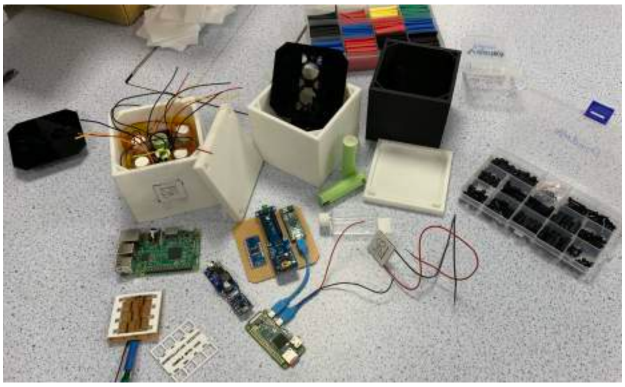

Fig. 3. Ophelos Phase-0 system before the assembly

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- *Final orbital system – Phase 2*

The second phase of the project will be carried out by a 3U CubeSat, allowing for bigger payload and more sophisticated subsystems. This part of the project will focus on a long-term observation of glioblastoma cancer cells, with an observation module inside the satellite. The project is a development from the GlioSat and GlioLab experience, both designed to observe the behavior of Glioblastoma cancer cells in extreme environments, and expanding their capabilities by being able to carry a wide array of payloads [7]

IV. LONG-TERM PROJECTS

The long-term initiatives have the main goal of establishing a complete program where students, in a time frame of approximately 2 years, will be involved in a real complete space mission. The full 2 years program will involve the students in different phases and at different levels. Basically the full program includes design, analyses, tests and in orbit operations of a satellite, normally CubeSat standard based. Similar hands-on activities are conducted overall the world and in Europe are strongly supported by European Space Agency [8].

To achieve these important goals and to get the chance to have interesting missions every two years the proposing team proceeded establishing an UoN Space group and several international cooperation.

A. UoN Space Group

Established in 2018, the UoN Space group aims to bring together existing expertise from across the University of Nottingham to focus on capturing research income around the technologies and sciences needed by the growing UK space sector. In coalescing this expertise, the team also anticipate training undergraduate, graduate, and post-doctoral researchers in the skills in demand by the space sector.

The University of Nottingham has wide ranging experience and research interests in Space Exploration, Space Technology and Manufacturing, observing the Universe, Space Biology, Space Pharmacy, Navigation and Earth observation.

The UoN Space group in particular is proposing several CubeSat missions in the different areas of research that will be developed in the near future by students and researchers at UoN.

B. International Cooperations

In the last two years several international cooperation have been established by UoN and international partners such as INPE (Instituto Nacional de Pesquisa Espacial), CEiiA, University of Beira Interior (UBI), University of Brasilia (UnB). The cooperation will allow students at UoN to get the chance to cooperate with foreign people and to put their own system in space starting from the second quarter of 2020.

- Cooperation with INPE-Brazil

The cooperation with INPE is actually based in two different projects: RaioSat and UbatubaSat-II. The RaioSat joint project aims to develop a 3-axis attitude determination and control subsystem (ADCS) for the nanosatellite RaioSat, a 3-U CubeSat designed by INPE/Brazil. The satellite's primary mission is to detect intra-cloud and cloud-to-ground lightning flashes simultaneously, specifically to provide complete lightning detection covering Brazil. This information is useful for predicting extreme weather phenomena that require high-resolution numerical weather prediction (NWP) models and high amount of observational data [9] Students at UoN will be involved in the design of both software and hardware to guarantee the three-axis stabilization needed to accomplish the mission.
The UbatubaSat-II cooperation involves also the Associação Ubatubasat (Ubatubasat Association) in Ubatuba (SP, Brazil). The association is the responsible of the Ubatubsat program who allowed students aged 9-16 years from the school Tancredo Almeida Neves, in Ubatuba (SP) to launch the piscosatellite Tancredo-1, one of the two first TubeSats ever launched[10]. In this second edition the young students will use a 1U platform to integrate their new payload and UoN students will support them designing the deorbiting mechanism. The launch is scheduled for the end of 2020.

- CEiiA and University of Beira Interior- Portugal

UoN is cooperating also with institution in Portugal with the aim of having a first space system in orbit with Soyuz in the second quarter of 2020. The CEiiA and UBI satellite, a 1U CubeSat, will test a new algorithm for ADCS magnetic stabilization developed in cooperation with Keldysh Institute of Applied Mathematics (KIAM). UoN will cooperate in the payload and in the system to guarantee the satellite deorbiting.

- Univeristy of Brasilia-Brazil

UoN is an active partner of UnB in particular with the Laboratório de Simulação de Controle de Sistemas Aeroespaciais (LSCSA) in different space activities such as LAICAnSat, the ADCS simulator and the Alfa Crux mission.

LAICAnSat is a platfrom for testing several payload using a HAB and a 3U CubeSat shape platform [11]

The ADCS simulator consist in an Helmoltz cage and airbearing table designed by students with the main goals of testing new algorithm and hardware for ADCS [12]

Alfa crux mission main goal is the design of narrowband communication satellites, compatible with defence tactical radios, and able to provide critical communication beyond radio targeting, and enable an M2M / IoT data network in remote regions with little infrastructure. The first technological demonstrator will be launched in the second quarter of 2020.

V. FACILITIES

Mechanical, Manufacturing and Materials Department has all the equipment needed to help the students to manufacture their own system starting from the 3D printer prototyping to laser cutting, water cutting and CNC machines.

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M3 is also investing in acquiring new facilities and software to implement the hands-on student experience. In the academic year 2019-20 a UHF, VHF, S band ground station provided by AlenSpace company will be installed. As told in the previous paragraphs also two different cubesatt simulators will be available for the students one provided by TheiaSpace and the other by OpneCosmos.

The setting facilities are not completed yet but shakers, anechoic chambers and vacuum chamber are yet available.

VI. Future Activities

Future activities at UoN are mainly based on the idea of establish the CubeSat UoN program, The program will offer the student the unique opportunity to work in a real space program from the beginning of their university career with some preliminary design up to the end of their academic course with the in orbit operation.

Acknowledgment

The authors want to thank students and colleagues at University of Nottingham involved in this educational experience and to all the international partners who are supporting the team in establishing a fruitful hands-on educational program at UoN.

A special thanks to Dr. Alastair Campbell-Ritchie, Dr. Richard Cobbs, Dr. David Hann, Dr. Paul Bathia, Jez Turner, and the Ophelos and PunchSat students.

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Spicing up your space education with cansats, rockets and hackathons – the SUN Recipe Book

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***Abstract*—The UK-based "Space Universities Network" (SUN) was formed in 2016 with the aim of enhancing the quality of learning and teaching by providing support and resources to the space science and engineering higher education community. It now has 60 members from 30 different Universities around the UK. SUN's objectives are to facilitate the creation of a skilled workforce of graduates who can meet the challenges of future scientific and commercial exploitation of space. The network addresses this need by helping to inspire students to join the space sector and ensuring they are well equipped at University to contribute. SUN enables the developing, sharing and promotion of effective practice and innovation in the delivery of university-level space science and engineering curricula. One of the ways that effective practice and innovation is disseminated is by the collection of case studies. In this paper, a collection of case studies from different members of the network is described.**

The case studies cover a wide variety of student activities run by staff and/or students including Satellite in a SodaCan (CanSat) competitions, water rocket and rocket building, earth observation data hackathons, astrodynamics workshops using GMAT software, lunar rover model building, cubesat projects, remote microscope investigation of samples, satellite applications data workshops and ESA 'drop your thesis' projects. For each case study, those running the activity completed a standard format template of 1-3 pages which describes: What was the purpose? How was it integrated into the curriculum (if at all)? How did it work? What materials do you need and how much did it cost in time and money? What problems were encountered? What feedback did you have? The paper describes each case study briefly. These are now publicly available on the SUN website (spaceuniversitiesnetwork.ac.uk) and are accessible to all. More cases studies are welcome and are being submitted. It is hoped that these will inspire other Universities who wish to spice up their space courses with some interesting recipes!

Keywords—higher education; case studies; resources;

I. Introduction

The world space economy is expected to grow to $400 billion by 2030 and the UK has ambitious plans to secure 10% of the global market, growing the space workforce by a further 100000 jobs. Training new space engineers and scientists is therefore critical. It is recognized that there is a shortfall in Science, Technology Engineering, and Maths (STEM) graduates. A UK accreditation body called the 'Institute of Engineering and Technology' has produced a report on skills, based on surveys of employers. These surveys established that 62% of UK engineering employers are concerned about graduate skills, and of those, 59% say that is because Engineering and technology degrees do not develop sufficient practical skills. 68% of employers are concerned that the education system will struggle to keep up with the skills required for technological change [1]. Against this backdrop, the UK-based "Space Universities Network" (SUN) was formed in 2016, with the aim of enhancing the quality of learning and teaching in Space Science and Engineering. SUN members wish to enable the development, sharing and

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promotion of effective practice and innovation in the delivery of university-level space science and engineering curricula. In previous work, the aims and objectives, evolution of the network, methods, evaluation of the network has been described [2]. In this work the network have collected together a series of case studies from different UK universities which describe examples of good practice in the field of space teaching and learning.

II. Background

The value of the Space Universities Network comes from the collective intention to advance learning in Space Higher Education, with a particular focus on space science & engineering. The objectives of the case studies were to share good practice by giving university staff and students the opportunity to briefly describe their experiences of certain innovative curricular and extra-curricular projects and exercises in a short format. Many of the projects are active learning-based projects involving the acquisition of practical skills as well as design and research skills.

For each case study, those running the activity completed a standard format template of 1-3 pages which describes: what was the purpose? How was it integrated into the curriculum (if at all)? How did it work? What materials do you need and how much did it cost in time and money? What problems were encountered? What feedback did you have? These questions were designed to elicit information which would be helpful to staff and students in other institutions who were thinking about setting up new activities. The aim was to have a suite of exciting projects which are easy to access (they are all publicly available on the SUN website). The projects cover both curricular and extra-curricular projects, as the same activity can be used in both ways in different Universities. For more details on each project, readers should go to the SUN website:

III. Astrodynamics with GMAT – University of Leicester

The University of Leicester have run an Astrodynamics Mission Simulation 10-credit module over 8 weeks (2 full afternoon computer lab sessions per week) using NASA's General Mission Analysis Tool (GMAT) [3]. The module is taught using a constructivist approach, in which students are found to be more likely to recall and understand concepts which they have discovered independently, than those taught directly. The 30-35 students are set problem questions over the 8-week period and are supported through these in the computer lab sessions by the lecturer and post-graduates. The module is concluded with a mission scenario given to teams of 4 or 5 where students build on the knowledge acquired in the taught elements and apply them to the design of a mission. E.g. plan a mission to Mars using the Phobos-rendezvous using minimum delta V.

Astrodynamics is the study of spacecraft motion, subject to both natural and artificially induced forces. It combines celestial mechanics, attitude dynamics and aspects of positional astronomy to describe spacecraft motion and enable the planning and analysis of missions. The Astrodynamics Mission Simulation module is associated with a third-year undergraduate module comprising 12 lectures and screencasts providing an introduction to astrodynamics. This Astrodynamics lecture module is not a prerequisite to the Mission Simulation module however both are very complementary.

This was a staff-led curricular module. The module was run over an 8-week period with 2 full afternoon computer lab sessions per week. The module consists of 6 stages:

1. Walk-through tutorial sessions
2. Introducing Simple Celestial Mechanics
3. Increasing Detail: Perturbations
4. Manoeuvres & Targeting
5. Advancing Beyond Earth
6. Workshop Assessment & Final Challenge

IV. Lunar Rover – University of Surrey

The University of Surrey 'Electronics and Amateur Radio Society' (EARS) sent a team to compete in the UKSEDS Lunar Rover competition to design and build a rover to achieve an objective set by the organisers. This was an extra-curricular project run by students who developed the rover over an academic year and competed in a final test day.

UKSEDS (UK Students for the Exploration and Development of Space) in tandem with various industrial sponsors runs an annual Lunar Rover competition open to university students in the UK. The goal is to design and build a working lunar rover able to complete a set mission. The lunar rover must be designed to fulfil requirements. For 2016 the mission was: to navigate into the bottom of a lunar crater, retrieve a soil sample, and return to the edge of the crater area. The rover must then return itself with the soil sample to the starting point. The competition entry was student led and the team comprised: 2 Space Engineering MSc students, 2 second year Electronic Engineering students and 2 first year Electronic Engineering students.

The team's activities were organised in accordance to the schedule set by UKSEDS to complete a PDR and CDR and finally the test day. The steps taken were as follows:

1. Assemble team for competition entry
2. Apply to enter competition
3. Start designing systems
4. Test designs for wheels/sample collection systems
5. Complete PDR
6. Integrate chosen designs together
7. Complete CDR
8. Complete electronics
9. Compete in final test day

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V. AIAA CANSAT COMPETITION – UNIVERSITY OF MANCHESTER

The Manchester CanSat Project was developed by a team of mainly 2nd and 3rd year undergraduate engineers. They took part in the 2017/18 AIAA & AAS CanSat competition (http://cansatcompetition.com/) held in Texas, USA, which they won. The team designed and built their CanSat to achieve the set mission of the competition over a year with help through funding from sponsors to pay for subsystem components and travel costs. They developed review documents describing progress through the year and performed multiple drops from a rocket to test the systems in the UK, and then travelled to the US for their test flight and presented the outcomes at a post-flight review.

The American Astronautical Society (AAS) runs the CanSat competition annually with the aim to give students an opportunity to design, build, test, launch and operate an engineering product, as opposed to designing a space-related product without any building or testing. The competition specifically is based on designing and building a satellite that fits within a cylindrical envelope of 310 mm length and 125 mm diameter (like a soda can). This project was organised as an extra-curricular activity within the ManSEDS society.

The project started with research and design, progressing to a Preliminary Design review and then followed by a Critical Design review, which required details of manufacture and test and evidence that it would meet the requirements. Good performance in the PDR allowed continuation into the CDR where the top 5 teams competed. This was followed by the test flight where the CanSats were launched and released by rockets at a launch site in Texas provided by the AIAA. Finally, a Post Flight Review was completed involving a presentation and questions.

VI. SPACE MISSIONS IN DEVELOPMENT – UNIVERSITY COLLEGE LONDON

University College London run a curricular 2-week research project into space missions that are currently in development/operation for their MSc Space Science and Engineering students. The students work in pairs and are required to submit a 2500-word report within 2 weeks of the task being set. The research activity is intended to fuel the interest of the students in space by giving them the opportunity to conduct in-depth research into a specific mission that is in development or in operation. The activity aims to improve teamworking skills, report writing skills and general research skills. This is a staff-led curricular activity.

The report must discuss the most innovative, ground-breaking aspects of the mission, the expected scientific discoveries and advance of knowledge it will bring, the technical challenges to be faced and how they will be resolved, mission relevancy and timeliness. Students conduct the research in their own time – they must first select their mission and check with their peers that nobody else is looking at the same mission. Once the mission is selected, they conduct further research into both the scientific objectives of the mission, the technological challenges it faces and how these have been overcome. Conducting this activity so early in the year allows for report writing standards to be established early to improve the quality of submissions later in the year.

VII. GEOSS/HACK SPACE HACKATHON – ESA

The European Space Agency (ESA) ran a Space Hackathon in partnership with the Group on Earth Observations. 30 participants split into 6 teams had 30 hours to create an open-source solution to 1 of 6 challenges focused around meeting the Sustainable Development Goals using Earth Observation data from the Global Earth Observation System of Systems (GEOSS) portal (https://www.geoportal.org/). The primary objective of the GEOSS/HACK hackathon was to challenge participants to develop innovative tools to use satellite data to benefit society, engage more people in the use of Earth Observation data and tackle the Sustainable Development Goals.

This was a staff-led extra-curricular challenge for students. At the GEOSS/HACK Space Hackathon there were 6 challenges that the participants could decide to undertake. Sourcing these challenges was very work-intensive. The challenges that were set to participants were as follows:

a. Designing for Accessibility - Make an application that maps accessibility information and allows the users to add new information about cities and points of interest.
b. Cloud Detection Game - Increasing the amount of classified data for machine learning. The goal is to develop a game where the player classifies Sentinel-2 image pixels.
c. Astro-ecology - Saving Earth's biodiversity. A key part of the system was developing software to automatically detect and identify animals and humans in aerial thermal video footage.
d. Connecting Arctic voices - Develop a tool to allow young people living in the Arctic to engage with satellite images, weather data and in-situ observations in new ways, to promote sharing of information with their Elders and help to identify data that could be used to predict environmental hazards.
e. Protecting the Forest - Develop a biodiversity monitoring tool to motivate local patrols in Madagascar to engage with satellite images and encourage them to contribute in-situ observations.
f. Understanding Child Malnutrition in Sudan using Geographical Data

The hackathon was held at ESRIN's headquarters in Frascati, Italy as well as being streamed to ESTEC in the Netherlands and ECSAT in the UK. At the end of the challenge, all participants were asked to present a 2-minute video, uploaded to YouTube, explaining their application plus

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a small description of their solution together with their code on github. The winning team were given prizes.

VIII. Micrometeoroid Impact, Damage and Shielding Activity – The Open University

The Open University run a curricular activity on impact damage and shielding of micrometeoroids using a remotely operated optical microscope. The Micrometeoroid Damage Equations are used to estimate the crater depth or maximum thickness of material that will be perforated by an impactor on a surface. The activity can be conducted with the microscope itself or using provided measurement data. The activity is intended for independent study and takes students roughly 3 hours to complete.

The activity is part of a space science module taught at the Open University as part of the MSc 'Space Science and Technology' programme. The activity is run through the Open STEM Labs (OSL) - a platform bringing interactive practical science to distance-learning students through the internet. Some OSL activities are open to all, some are restricted (see http://stem.open.ac.uk/study/openstem-labs).

Micrometeoroids present a hazard to spacecraft and astronauts. Cratering events occur at hypervelocity i.e. greater than speed of sound in the target material. The purpose of the case study is to highlight the importance of designing for damage mitigation from micrometeoroids. Students investigate the effects of micrometeoroid impact of different sizes on spacecraft materials and a method for reducing the mass of protective shielding. The remote optical microscope gives students the opportunity to engage practically with the subject.

This was a staff-led curricular activity with a focus on student independent learning. The optical microscope can be used to measure the dimensions of the impact crater [Note: This is an optional step as a data sheet is provided with all the measurements]. The activity sheet contains several problem questions to answer using data obtained from the remote optical microscope. Answers are provided for the students to assess their understanding.

IX. Water rocket competition – University of Bristol

Based on a suggestion by Kingston University London, who run this as a curricular competition, Bristol SEDS ran a water rocket competition in October 2017 with the aim to have multiple teams competing to design and build water rockets. 5 teams of 3-4 students competed, each producing a design and building a rocket to carry an egg payload and then launched their rockets, once on a test launch day and once again being judged on competition day.

A water rocket is a simple and safe way of demonstrating the principles behind rocket propulsion. The competition aimed to get teams of students to design the nose cone, tail fins and use a pressure vessel, mainly a 2-litre fizzy drink bottle. The teams would have to be able to design, build and launch and recover their water rocket carrying an egg payload and achieve the highest possible altitude, and perform both these tasks repeatably. The rocket is partly filled with water and pressurised using a pump while attached to a multi angle Full Bore launcher. Once ready for lift-off, a launch pin is pulled out from the launcher and the rocket is propelled into the air. The rocket needs a parachute that will deploy at max altitude and allow the rocket to be recovered. The objective was to have fun, develop teamwork, design iteration and manufacturing skills.

The process for organising the competition was:

1. Present project to society, organise teams, hand out documentation on how to build water rockets (http://www.npl.co.uk/upload/pdf/wr_booklet_print.pdf)
2. Provide resources / set maximum budget that teams can use for buying resources
3. Run workshop / assistance sessions twice a week
4. Run a test launch weekend
5. Run final launch weekend
6. Judge competition
7. Run final presentation

X. Project SunrIde - Nova Rocket Innovation Design Engineering - University of Sheffield

Project SunrIde was the first student-led rocket design engineering team from the U.K. to compete in the Spaceport America Cup (SAC) https://www.spaceportamericacup.com/. in 2018. This is held in Las Cruces, New Mexico and the team competed in the 10,000ft category solid propellant commercial off-the-shelf motor (COTS) competition. The team had to design and manufacture a sounding rocket, which they named 'AMY', after Britain's first aviator and alumna of the university, Amy Johnson. In this competition round rocket "AMY" (Friday 22nd June 2018) reached an apogee of 10,017ft and team SunrIde won the prestigious James Barrowman Award for Flight Dynamics, beating more than 140 university teams from the USA, Canada, Europe and Asia. In 2019, the success of the University of Sheffield inspired three more universities from the UK (Bath University, Cranfield University and Open University) to participate in SAC. The SunrIde team successfully built and launched a completely in-house rocket "HELEN" named after the University of Sheffield alumna Helen Sharman - the British astronaut. The SunrIde launch (Friday 21st June 2019) beat the UK's 19 year long standing national altitude record. HELEN reached an apogee 36762 ft, with a top speed of 2.67 Mach in just 4 seconds and acceleration of 29G.

SunrIde is part of Sheffield Space Initiative (SSI). Since the project's inception in 2017, SunrIde was formed by academics from the Automatic Controls and Systems Engineering (ACSE) and Mathematics and Statistics

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Departments of the University of Sheffield. Now, alongside from SunrIde, SSI consists of four more exciting space related projects, i.e. the Sheffield University Nova Balloon Lifted Solar Telescope, MarsWorks, Avalon ROV and the Sheffield University Nova Satellite.

SunrIde consisted of Undergraduate and Masters' students across the Faculty of Engineering (ACSE, MecEng, EEE, BioEng, Material Science, Aerospace), Faculty of Science and students from Hallam University. The team composed of 5 research sub-teams: Design and Propulsion, Recovery Systems, Avionics, Payload, Structures and Manufacturing and 1 back-office subteam on Media.

Without any prior experience in rocketry, building a high-power rocket from scratch proved to be a daunting task. The team had to rely on their communication skills in order to bring students from different engineering backgrounds together. A network of experts in academia and industry was established in order to develop the overall concept and provide support throughout.

XI. Drop your thesis– University of Cranfield

Cranfield University have supported a successful application to the European Space Agency (ESA) 'Drop your Thesis' (https://www.esa.int/Education/Drop_Your_Thesis/) competition. In this competition, selected groups of students have the opportunity to conduct their final experiment in the 146m ZARM Drop Tower in Bremen where gravity levels of 10^{-6}g can be achieved. Two different modes exist for the experiment, the drop mode (4.74 seconds of microgravity) and the catapult mode (9 seconds of microgravity).

The 'Land 3U' microgravity experiment sought to quantify the energy dissipation during touchdown on low-gravity bodies, such as asteroids, to explain the apparent disagreement between low energy dissipation measured during touchdowns on Philae (ESA) and Hayabusa (JAXA) and the very high energy dissipation measured by previous experiments in microgravity.

This was a PhD student and academic supervisor-led curricular activity. The group was made up of 5 MSc students from Cranfield University's 'Astronautics and Space Engineering' course and 1 PhD student. The Land 3U team's experiment focused on Unpowered CubeSat Landing for Asteroids. The ZARM Drop tower was ideally suited to simulate this microgravity environment, encountered by small asteroids approximately 100m diameter. The 1U CubeSat mock-up structure mimicked a 3U landing (~3 kg) with a velocity of 100 to 200 mm/s. The velocities before and after the touchdown were recorded enabling calculation of the ratio of linear momentum loss (the coefficient of restitution, "ε"). These calculated values allowed the energy dissipation to be quantified.

In some cases, it is possible for the teams to use special equipment (e.g. CCD cameras, heating/cooling devices) available from the drop tower operator. These are assessed on a case-by-case basis and may carry associated costs for the team. Education Drop Tower Campaign was a 2-week long campaign in October-November in Bremen, Germany. The first week is dedicated to integration and ground testing of the equipment. In the second week, the team is allocated 5 launch opportunities for the experiment. The students were able to submit a paper to a conference to report on their findings.

XII. Conclusions

The Space Universities Network is a community of space science and engineering Higher Education staff at UK Universities. This network has collected 10 case studies from different Universities around the UK to share good practice and motivate students to join the space industry. Further details of the case studies can be found at https://spaceuniversitiesnetwork.ac.uk/resource-bank/case-studies. It is hoped that staff and students from other institutions may benefit from this collection of recipes for learning about space.

Acknowledgements

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The ESA Education Programme and its ESA Academy

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***Abstract*— The European Space Agency's Education Programme, composed of the Primary and Secondary STEM Education Programme for younger students, and the ESA Academy Programme for university students, is strongly committed not only to inspire, but also to actively engage students. The Primary and Secondary STEM Education Programme's aim is to use space as a teaching context to enhance youngsters' literacy, skills and competences as well as to develop the pupils' core values and attitudes in STEM disciplines, and to inspire and to motivate them to pursue studies and careers in the STEM sector. The ESA Academy, the overarching education programme for university students, uses space as the subject, and is designed to equip the next generation of professionals working in the space sector with 21st century skills and competences, with the objective of enhancing their employability, and stimulating their creativity, innovativeness and entrepreneurship.**

The ESA Academy encompasses a portfolio of hands-on 'Space' projects ranging from scientific and technology-demonstration experiments to be run on a number of different professional platforms, to small satellite missions such as CubeSats; complimented by a varied portfolio of training sessions given by space professionals coming from all fields of ESA's expertise, as well as from space industry and academia.

Every year hundreds of students participate in ESA Academy's activities, with students participating in launch and experiment campaigns conducted at state of the art facilities located at several centres of excellence around Europe, and amassing an impressive portfolio of space-related and research experience.

In order to be eligible to participate in the ESA Academy programmes, students must be nationals of one of the 22 ESA Member States, or Canada or Slovenia. Operating with students coming from across 24 different states and at different levels of their university studies, comes with a unique set of challenges, including, but not limited to, interacting with different national academic approaches, different academic schedules, student engagement levels, gender and inclusiveness, and team funding. The Education Office has risen to these challenges and has developed a comprehensive and inclusive programme framework, which continues to develop as new challenges and new opportunities are identified.

The ESA Academy is moving forward with the confidence that the future generations of space professionals in the ESA Member States may benefit from getting the best training and hands-on experience to support the future of the European space sector. The ESA Academy aims to reinforce, and even to further develop, its offering of programmes and training sessions over the coming years.

Keywords*— ESA, Tertiary Education, Hands-on activities, Training and Learning, University students, Education, Extracurricular.

I. What is the ESA Education Office?

The ESA Education Office organises and conducts educational activities for students (i.e. not for professionals). It develops the Agency's education policy and ensures its implementation. Furthermore, the Office organises and manages education activities in collaboration with other ESA directorates, with the goal to federate all ESA educational activities, and to become the single point of contact for the outside world for all the Agency's 'education matters' [1].

II. What is the purpose of the ESA Education Office?

The ESA Education Office is responsible for developing and implementing ESA's corporate education policy, which is designed with the purpose of supporting Europe's need of encouraging an increasingly knowledge-based society by motivating young people to enhance their literacy in science and technology, including associated applications, and to pursue careers or research in these fields, in particular in the space domain. To this end, it collaborates with ESA Member States' institutions to attract the best talents to space activities [1].

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III. Where does the Education Office sit within the ESA Framework? And where does it sit within the overall European Space Effort?

The Education Office is part of the ESA Director General's Services, and has strong links with all ESA directorates. Many Education Office projects are organised in partnership or collaboration with other ESA directorates, national space administrations, European space industry, national administrations in charge of formal education, and academic institutions. The ESA Education Office periodically reports to the ESA Council and to the Advisory Committee on Education (ACE), the latter of which is composed of representatives from all ESA Member States, in this way ESA Member States, as stakeholders, are debriefed and may offer their feedback.
The beneficiaries of the ESA Education Office activities may be regarded to be both the direct 'participants' (i.e. the students and the teachers which partake in the Office's initiatives), as well as the European space industry and organisations in general, which benefit from the increased motivation and literacy of their future workforce.

IV. Why and when was the Education Office established?

Education was included as one of the fundamental activities of ESA from its very conception in 1975. The foundation document of the Agency, the ESA Convention [2], lays out education as one of the mandatory activities, and thus one that all Member States shall participate in. Consistently with its mandate, the Agency has long been involved in various education activities.
The Education Office itself was formally established in the late 1990s [3], followed shortly by the implementation of the Advisory Committee on Education (ACE), a forum of education experts representing all ESA Member States, which had its first meeting in 2001 [4], and that was definitively established in 2002 [5].
The mandate of the Education Office has remained largely unchanged since its establishment, remaining consistent to its declared initial objective to: "coordinate a European Space Education programme aimed at challenging and motivating a large number of young people through active involvement in exciting projects in order to enhance their literacy in science and technology in general, and space related matters in particular" [3].
The initial set of initiatives of the Education Office included the European Student Moon Orbiter (ESMO), the continuation of parabolic flight campaigns for student experiments, and the establishment of European Space Education Resource Offices (ESEROs). In the following years the Education Office was involved in educational satellite launches (SSETI Express, 2005 [6], YES2, 2007 [7]) and engaged in a considerable expansion of its portfolio of hands-on programmes, see section X.
Building upon the heritage from the many educational initiatives undertaken in the past, the ESA Education Programme formally took shape in 2004, with the introduction of the "ESA Education Policy" ESA/ADMIN/IPOL(2004)8 which established the founding principles to implement the ESA Education Programme [1].

V. Where is the ESA Education Office based? And what are the facilities it uses?

The bulk of the ESA Education Office's activities are coordinated from two sites, the European Space Research and Technology Centre (ESTEC) in the Netherlands, and the European Space Security and Education Centre (ESEC-Galaxia), in Transinne, in Belgium. However many activities take place in other places distributed around all Europe, see section X.
The Education Office organises and hosts various activities at both ESTEC and ESEC-Galaxia, such as teacher training workshops, training and selection workshops for university student teams, training and learning sessions (mostly at ESEC-Galaxia), and technical work, such as CubeSat testing (at ESEC-Galaxia).
At the ESEC-Galaxia site, the ESA Education Office has established dedicated infrastructure consisting of:

- A Training and Learning Facility (TLF), which can also operate as an educational Concurrent Design Facility (CDF).
- An e-Technology Laboratory for teacher training
- A CubeSat Support Facility (CSF)

The TLF is a modern technical facility, which is capable of hosting up to 30 students and 8 trainers for various types of training sessions, and is equipped with smart boards and networked computers for interactive learning. Further information can also be found in the 3rd SSEA conference paper "The ESA Academy's Training and Learning Programme", Marée et al.
The CSF consists of an ISO 8 clean room laboratory to support small satellites integration, inspections, and testing, equipped with a thermal vacuum chamber and a 20kN electrodynamic shaker.

VI. How is the Education Office organised?

In its current set-up, the Education Office consists of two units, the STEM (Science, Technology, Engineering and Mathematics) Education and Outreach Unit, for the Primary and Secondary school level and outreach activities, and the ESA Academy Unit, for the university education level.

VII. What are main activities of the STEM Education and Outreach Unit?

The STEM Education and Outreach Unit carries out a broad range of activities, aimed at offering education and training opportunities for primary and secondary school teachers and pupils, as well as offering a backbone of outreach services conceived to support not only primary and secondary education, but also the Education Office as a whole.
The approach undertaken to organise the primary and secondary education activities is based on the concept that "Space is the Learning and Teaching Context" which is utilised

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to create educational activities aiming at teaching subjects related to all STEM disciplines.
The activities of the Primary and Secondary STEM Education and Outreach Unit are built around the programmatic backbone consisting of the ESERO Programme.
The ESERO Programme is conducted in partnership with ESA Member States' national space administrations and with their national administrations in charge of formal education, and it aims at developing and maintain a network of national and regional "European Space Education Resource Offices", which shall soon cover all ESA Member States.
The ESERO offices have assigned the task to provide both teacher training and space-related STEM classroom resources, tailored to national education curricula.

Further to coordinating the activities of the ESERO offices, the primary and secondary education activities of the STEM Education and Outreach Unit encompass the following:

1. Teacher training
   ESA Education develops several different activities to support the integration of space topics in the classroom. ESA provides regular teacher training workshops, held either at ESTEC, and/or at ESEC-Galaxia, and supports the additional teachers training offered at Member States level by the ESERO offices.
2. School projects
   The STEM Education and Outreach unit manages an attractive (and still expanding) portfolio of educational and interdisciplinary initiatives that aim to help young people increase their STEM competences and skills, including scientific methodology, teamwork and critical thinking. These include the creation of original material for classroom resources, and projects such as CanSat competitions, the Moon Camp Challenge, and Climate Detectives. Most of the products and activities created as school projects are also offered or shared with the ESERO offices, in order to maximise the educational return.
3. ESA Education outreach initiatives
   The outreach activities provide on the one hand, general outreach about all ESA Education activities (delivered through the whole ESA Education web portal, social media and other platforms), and, on the other hand, to form the bridge between the primary education projects and their target of students and teachers. These latter activities include the production and maintenance of the ESA Kids website, which includes the management of the ESA Kids mascot, Paxi.

VIII. WHAT IS THE ESA ACADEMY? AND HOW IS IT ORGANISED?

The ESA Academy Programme constitutes the ESA Education Office's 'offer' for university students.
Like the Education Office in general, the ESA Academy is designed to complement academic education, and to enhance students' educational experience by allowing them to benefit from a substantial transfer of practical and theoretical knowledge from space professionals.
Correspondingly to the approach adopted for Primary and Secondary Education ("Space is the Learning and Teaching Context"), the approach for ESA Academy is "Space is the Subject", meaning that all programmes and activities offered by the ESA Academy are directly space related.
The whole portfolio of opportunities offered to university students constitutes the ESA Academy Programme, which is based on two interconnected pillars:

1. Training and Learning Programme
   The Training and Learning Programme (TLP) created and delivers a portfolio of training sessions for university students, typically lasting 4-5 days each, conducted at a dedicated Training and Learning Facility (TLF). See section IX
2. Hands-on Programme
   These include the full participation of university students in all aspects related to space projects. Students are engaged in designing and developing small satellites and/or experiments that can be operated on various platforms, such as balloons, sounding rockets or parabolic flights. The hands-on programmes often include project-related workshops and training offered by experts. See section X

Further opportunities offered to university students (individual or teams) consist in:

1. Accessing test facilities
   The student teams engaged in the hands-on programmes are supported with access to professional test facilities, located at ESEC-Galaxia, at ESTEC, or, sometimes, at other premises.
2. Participation in conferences and workshops
   ESA's Education Office supports student participation in conferences and workshops, including the regular meetings of ELGRA (European Low Gravity Research Association) Symposium and the International Astronautical Congress.

IX. WHAT IS THE TRAINING AND LEARNING PROGRAMME?

The Training and Learning Programme offers a portfolio of 4-5 day training sessions on disciplines encompassing many fields of space expertise. These training sessions are developed and delivered by experts, who are specialists in their own specific domain. These trainers are usually ESA employees or retirees but may also be specialists from other space agencies, academic institutions, universities or space industry. Up to 20 training sessions are organised every year at the TLF.
The TLP offers students the chance to complement their university led education with additional training in subjects which may not be covered by their traditional university curricula. The ESA Academy coordinates and funds the development and the delivery of the training sessions, as well as sponsors the travel of the selected students (ceilings may

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apply), including the accommodation and meals for the duration of the training session. Up to 30 students participate in each session.
The full list of training session, including details on how to apply are available on the ESA Education website: www.esa.int/Education/ESA_Academy/Current_opportunities.
Further information can also be found in the 3rd SSEA conference paper "The ESA Academy's Training and Learning Programme", Marée et al.
In addition to supporting the conduct of the training sessions of the TLP, the TLF is also utilized to support the conduct of training courses or workshops specifically dedicated to the student teams engaged in the hands-on programmes (for instance workshops on lessons learned from the different programmes, and/or to share in-flight experience).

X. What are the hands-on programmes of the ESA Academy?

The hands-on programmes of the ESA Academy are designed to give students, usually organized in teams, the opportunity to put their education into practice, by engaging in real space projects. This gives them the opportunity to experience the full space project life cycle, starting from the definition of their mission or experiment concept, and passing through the preparation, the submittal, and the defence of their proposal, and, if selected, by engaging in the design, development, manufacturing, assembly integration and testing, and conducting the experiment or satellite mission operations, and analysing the results. Finally, the students are also encouraged to present their projects and their experience at international conferences and in scientific or technical magazines or journals.
In general ESA Academy sponsors individual students, or teams (depending on the programme) to attend the various events and reviews associated to the programme in which they have been selected to participate, as well as it offers the launch or access to the platforms where the experiments are operated.
The ESA Academy also provides support in terms of offering technical mentoring and by reviewing the students' documentation in conjunction with the major review milestones. In general, student teams are responsible for gathering the funds for the development and procurement of their own hardware.
In a few cases testing is also offered.
In general, participation in the programmes is through competitive selection. Student teams or individuals are invited to submit proposals, and may be invited to participate in further selection events (workshops or teleconferences) before the final selection is made.

A. European Student Earth Orbiter (ESEO)

ESEO is an educational micro-satellite. ESEO follows on from the SSETI mission (launched 2007); it was initially conducted concurrently to the deferred ESMO mission (put on hold in 2012).
University student teams have been engaged in ESEO during the whole project lifecycle, since the definition of the mission concept up to launch and mission operations. The student teams were supported throughout the project with reviews carried out by ESA and industry experts, as well as by participating in dedicated training sessions, seminars, and workshops on different aspects of the ESEO mission.
The satellite is around 50kg, with a geometrical envelope of about 33x33x63cm (plus antennas).
In the Phase C/D/E (the final part of the ESEO Programme), student teams from 10 different universities in eight member states developed different equipment of the spacecraft, including the whole payload complement, and contributed to several system level tasks. Students were involved in the spacecraft assembly integration and testing, and in the definition of the mission operations.
The university student teams were coordinated by an industrial prime contractor and system integrator, ALMASpace (itself a university spin-off), that in 2015 become part of SITAEL S.p.A.
The university student team contributions to ESEO include the on-board electrical power distribution unit, an L-band radio amateur transmitter, an S-band transmitter, a GPS, optical cameras, a Langmuir Probe and a Tritel sensor, a deorbiting mechanism, an attitude determination system, the Mission Control Centre and its related ground station, a back-up mission control ground station, and a ground station dedicated to receiving the s-band transmissions.
ESEO was launched on the 3rd of December 2018.

B. Fly Your Satellite! (FYS)

The FYS Programme supports university student teams engaged in the design, assembly integration and testing, launch and operations of CubeSats.
The teams participating in the FYS Programme receive specialists' supervision in conjunction with project reviews, as well as specific training sessions, support for testing (expertise and/or access to test facilities), and eventually the launch opportunity. The university CubeSat teams engaged in the FYS Programme have the opportunity, under the supervision of ESA specialists, to get acquainted also with the methodologies and standards adopted by ESA in its programmes, and get the opportunity to familiarise with the standards and requirements applicable to CubeSat missions (tailored, as needed).
FYS is a recurrent programme, which is now entering its third edition. The first edition ran from 2013 to 2016, and supported six university built CubeSats. Three of the selected Cubesats were launched in April 2016, and another one was deployed to orbit from the International Space Station in October 2015. The currently ongoing second edition of FYS (started in 2017), is supporting six teams, which at the moment are preparing to enter the testing phase of their satellites.
The CubeSats participating in FYS may be launched on a variety of different launchers, including being deployed to orbit from the International Space Station (ISS).
A FYS team consists of at least eight students, at least four of which should be at master's level or higher. The length of programme participation depends on the entry level of the CubeSat, but it is typically expected to be about 3 years.
At the time of writing, the call for applications for the third FYS edition is open until the 13th of October 2019, and it is dedicated to CubeSat teams at 'entry level 2', i.e. those with a

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design mature enough to proceed to prepare the assembly integration and testing campaign.

C. Spin Your Thesis! (SYT)

The SYT Programme supports university teams through the design, testing and operation of experiments in a hypergravity environment making use of ESA's Large Diameter Centrifuge (LDC) located at ESTEC. Experiments may be operated under the acceleration of 1 to 20 g, for periods of 'minutes' up to 2.5 days.

Typical experiments include investigations in biology, biochemistry, fluid dynamics and materials sciences.

A SYT team consists of two to four students studying at master's level or higher. As with all 'Your Thesis!' programmes the experiment should also be an integral part of the student's syllabus. Each year typically two teams are selected to participate. The duration of one cycle of the programme is approximately 1 year (from selection until experiment results).

The SYT Programme has been running since 2010, and is now entering its 11th cycle. At the time of writing, the call for proposals for the next edition of SYT is open until the 2nd of December 2019.

D. Spin Your Thesis! - Human Edition! (SYT-HE)

The SYT-HE Programme supports student teams through the design and realisation of non-invasive experiments performed on human test subjects exposed to an increased gravity environment.

The test subjects may be asked to perform certain body movements or exercises. The programme makes use of the Short Arm Human Centrifuge of the DLR's envihab-facility, based near Cologne (Germany).

A SYT-HE team consists of four to six students studying at bachelor's level or higher. The duration of one cycle of the programme is approximately 1 year (from selection until experiment results).

The first cycle of SYT-HE took place in 2018, with three teams participating.

E. Drop Your Thesis! (DYT)

The DYT Programme supports student teams through the design, testing and operations of an experiment to be performed in micro-gravity conditions. This programme utilises the ZARM drop tower, in Bremen (Germany), where experiments can experience micro-gravity conditions at 10-6 g for periods of either 4.74 seconds, or about 9.3 seconds (depending on the 'launch mode' utilised in the drop tower).

A DYT team consists of two to four students. Each year typically one team or two teams are selected. The duration of one cycle of the programme is approximately 1 year and 4 months (from selection until experiment results).

DYT has been running since 2009 and is now entering its 12th cycle. At the time of writing, the call for proposals is open until the 20th of October 2019.

F. Fly Your Thesis! (FYT)

The FYT Programme supports student teams through the design, testing and operation of an experiment to be conducted in 'weightless' conditions, on board parabolic flights. This programme makes use of the Novespace Airbus A310 Zero-G aircraft, operated from Bordeaux. The experiments may be operated automatically, or manually by the experimenters (who may also fly onboard the aircraft), and are exposed to 31 parabolas per flight, with three flights per each parabolic flight campaign. Each parabola exposes the experiments to variable acceleration levels, cycling between about +/-2g (soon before and after the weightlessness period of the parabola), and about +/-0.05g during the weightlessness period, which lasts around 20 seconds per parabola.

Experiments conducted during the FYT campaigns have included a large variety of research areas, including fluid physics, material sciences, human physiology, neurophysiology, and psychology, as well as technology demonstrations performed as precursors to spaceflights.

A FYT team consists of four or more students, studying at master's level of higher. Each year at least two student teams are selected to participate. The duration of one cycle of the programme is approximately 1 year and 6 months (from selection until results).

FYT has been running since 2009 and it is now entering its 7th cycle. At the time of writing, the call for proposals is open until the 6th of October 2019.

G. Orbit Your Thesis! (OYT)

The OYT Programme supports student teams through the design, testing and operation of a small experiment to be operated on board the ISS for up to four months.

Experiments are to be conducted in the "ICE Cubes" facility, developed and operated by Space Applications Services.

The OYT Programme started in December 2018, with the selection of one experiment, which is due to be launched to the ISS in April 2020. OYT is expected to become a recurrent programme. The duration of the first cycle is expected to be approximately 2 years (from selection until end of operations).

H. Rocket/Balloon Experiments for University Students (REXUS/BEXUS)

The REXUS/BEXUS Programme is realised under a bilateral agreement between the Swedish National Space Agency (SNSA) and the German Aerospace Centre (DLR), and supports student teams through the design, testing and operation of their experiments to be flown on a sounding rocket or a stratospheric balloon.

The Swedish share of the payload has been made available to students from any ESA Member State (plus Canada or Slovenia), through an agreement with the ESA Education Office. DLR, SSC, ZARM and ESA all provide technical support to the student teams.

Two rockets and two balloons are launched each year, reaching approximately 80km and 30km respectively. If 'de-spun', during their ballistic flight the rockets can provide up to 2 minutes of reduced gravity, while the balloons may remain at their float altitude for 1-5 hours.

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A REXUS or BEXUS team consists of at least four students, and each year between eight and 12 teams are selected for the ESA/Swedish part of the programme. The duration of one cycle of the programme is approximately 1 year 2 months for BEXUS experiments and 1 year 7 months for REXUS experiments (from selection to experiment results).
The rockets and balloons are both launched from SSC's Esrange Space Centre, near Kiruna, Sweden.
The REXUS/BEXUS Programme was formalised in 2007 and is now entering its 13th cycle. At the time of writing, the call for applications is open until the 14th of October.

I. Fly a Rocket! (FaR)

The FaR Programme is realised under an agreement between the ESA Education office, the Norwegian Centre for Space Related Education (NAROM) and the Norwegian Space Agency. This programme gives individual students the opportunity to participate in an online training course before attending a one-week intensive sounding rocket campaign at the Andøya Space Centre in Northern Norway.
During the campaign students are offered the opportunity to apply the theoretical information they learnt during the online course, as well as during dedicated lectures. The students are organized into disciplines teams (GPS & Simulation, Telemetry and Data Readout, Payload and Sensor Experiment) and prepare the payload and launch facilities themselves. The execution of the launch operations is completely executed by the students (under close supervision of the Andøya Space Centre staff).
This is the only hands-on programme for which students apply as individuals.
The programme is currently ran biennially, and up to 24 students are selected to participate in each edition. The duration of one cycle of the programme is approximately 10 months (from selection until results).
This programme is designed for undergraduate students in their first and second year of university studies, and it is conceived to 'fill the gap' between high-school activities and the more advanced hands-on activities of the office.

The pilot cycle was completed in 2017, and the second edition was completed in 2019. The next call for proposals is expected to be announced in summer 2020, with the launch campaign in 2021.

XI. What are the criteria to participate in a training session or hands-on activity and what does the ESA Academy offer students?

Each programme, both TLP training sessions and hands-on activities, has its own requirement for the current education level of the students (e.g. Bachelor, master, PhD) and sometimes specific subjects (e.g. engineering, sciences). Many of the hands-on programmes also have requirements on team size and composition.
However, in general to participate in an ESA Academy Programme, and to receive ESA sponsorship (mostly for travels related to key events of the programme), a student must:

- Be a national of an ESA Member State, Slovenia or Canada.
- Be enrolled as a full time student.
- Be between the ages of 18 and 32 (inclusive).

Additionally for the hands-on programmes students must be studying in an ESA Member State, Slovenia or Canada

XII. What are the participation statistics in the activities of the ESA Academy?

Since the creation of the ESA Academy in 2016, nearly 2500 students have directly participated in its programmes. The cumulative programme reach (i.e. running total) can be seen in Figure 1.
Beyond the direct participants, it is estimated that thousands of other students have been indirectly reached either through their contribution to the work of the student teams officially selected for participation in the hands-on projects, or through outreach efforts both direct (i.e. by ESA Education) and indirect (i.e. by other students).

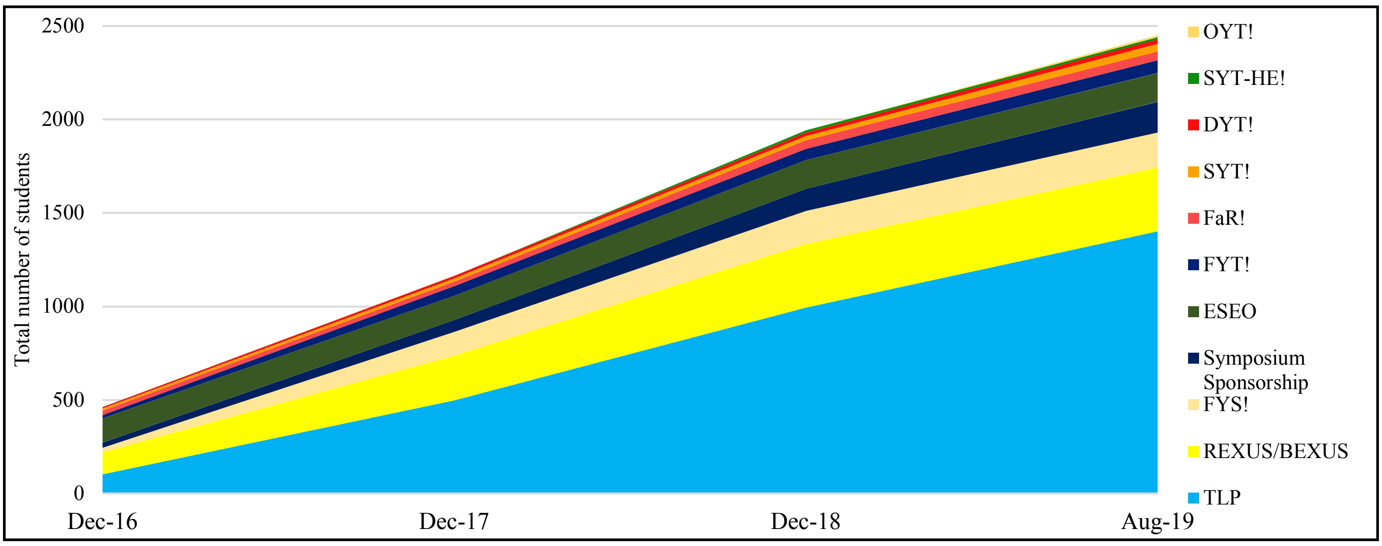

Figure 1: Cumulative participation numbers in ESA Academy programmes (direct programme participations since March 2016)

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From a 2017 survey of the REXUS/BEXUS alumni [8], numerous pieces of anecdotal evidence and through structured TLP feedback, it can be seen that participation in the ESA Academy programmes is well appreciated and helps students further their career and understand the role that they can play in the space industry.

The survey alone showed a wealth of resulting publications, a participant satisfaction rate of 99.1%, and 92% of the students after their participation increased their interest in pursuing a space related career. At the time of completing the questionnaires, 65% of the respondents also reported that they were already engaged in space-related employment, distributed in nearly the whole European space sector, and some in relatively high ranking roles.

XIII. What have been the recent challenges and developments for the ESA Academy?

The ESA Academy is always looking forward to opportunities and challenges that will be faced in the future of the European space sector, and adjusts and develops its offer accordingly.

In the recent past, the ESA Academy has considerably expanded its portfolio of opportunities with the addition of the Training and Learning Programme, which adds significantly to the knowledge transfer from agency and industry experts to students, addressing key issues around transfer and retention of knowledge in Europe.

The TLP itself has also rapidly developed a portfolio of activities based around ESA competencies and European needs, including both strategic and tactical planning.

Furthermore the Academy has added new programmes:

- Fly a Rocket! – which 'fills the gap' between high school activities and more advanced hands-on programmes.
- Orbit Your Thesis! – which takes further advantage of the ease of access to the International Space Station in order to utilise it as an educational platform.
- Spin Your Thesis! - Human Edition – which offers the opportunity to students interested in human space physiology to conduct hands-on experiments on human subjects, and to familiarise with the problematics related to the long-duration human space missions.

Last, but not least, it is important to recall that the ESA Academy, and the Education Office in general, maintains its commitment to equality of opportunity.

XIV. What are the future challenges/developments for the ESA Academy?

In the future, the ESA Academy will further evolve its educational offer, and will tailor its effort to meet the future needs of the European space sector. The ESA Academy is well placed to build on the mature and solid foundation of its Hands-on Programme and on the expanding portfolio of training sessions of its Training and Learning Programme.

It is envisaged that the ESA Academy, and the ESA Education Office as a whole, in collaboration with the European space community, will continue to identify and to address upcoming needs and will help to provide the next generations of space professionals with the necessary skills needed to tackle the new challenges. These challenges and needs may include climate research, resource utilization and management, space situation awareness, and future long-term manned missions (return to the Moon and Mars missions). It is envisaged that new opportunities may be created through further fostering of relationships and collaborating with other ESA directorates, and also with industrial, academic, and EU or international partners.

The ESA Education Office aims to develop its long and medium term strategy to support the educational community to prepare for "jobs that have not been created; for technologies that have not yet been invented; to solve problems that have not yet been anticipated" [9].

Acknowledgments

The ESA Education Office would like to acknowledge all partners and trainers involved in the ESA Academy programmes, because their enthusiasm and knowledge makes all these opportunities possible.

Furthermore the authors would like to thank all their colleagues of the ESA Academy team, because their competence and dedication are key to ensure students can get the best possible benefit from their participation in the ESA Academy Programme.

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The ESA Academy's Training and Learning Programme

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***Abstract*— The ESA Academy Programme is the overarching framework of activities provided by the ESA Education Office for university students from ESA Member States, Canada and Slovenia. The purpose of this programme is to complement and enrich the students' traditional university education through a suite of hands-on and training activities, enabling direct transfer of knowledge from agency, academic and industry professionals as well as access to world-class facilities.**

The ESA Academy aims to improve students' skills and to boost their motivation, enabling them to pursue careers and join opportunities within the Space sector and/or within other Science, Technology, Engineering or Mathematics (STEM) subjects and to bridge the gap between studies and professional life.

The Training and Learning Programme is one of the two core pillars of the ESA Academy. This programme offers a portfolio of training sessions covering different areas of ESA expertise.

Attendance at the training sessions is by competitive application. Selected university students are sponsored for travel and accommodation and get documents allowing them to claim ECTS credit to their Universities. More than 50 training sessions have been delivered since March 2016. Existing training sessions are periodically redelivered and new training sessions are under development to enrich the existing portfolio.

This paper presents the ESA Academy's Training and Learning Programme, gives an overview of its portfolio of training sessions, and provides some statistics and feedback from participants. Training session development and related challenges as well as possible e-learning opportunities are also discussed.

Keywords*— *ESA, ESA Academy, Tertiary Education, Hands-on activities, Training and Learning

I. The Training and Learning Programme within the ESA Academy

The ESA Academy Programme [1] is the overarching framework of activities provided by the ESA Education Office for university students from ESA Member States, Canada and Slovenia. The Training and Learning Programme is one of the two pillars of the ESA Academy, it has been operational since 2016 and aims at complementing the typical academic education in space-related disciplines offered in universities. Two of its main objectives consist in attracting, to the space sector, students that will constitute the next generation of professionals, and create opportunities to improve their competence and skills, by transferring knowledge, know-how, and familiarity with professional standard practice in all fields of ESA expertise. ESA Academy has the ambition to contribute to better prepare the future workforce for the space community of the ESA Member States, and to help university students to get acquainted with the opportunities offered by the space sector. Further information can also be found in the 3rd SSEA conference paper "The ESA Education Programme and its ESA Academy", Marée et al.

The Training and Learning Programme (TLP) offers a portfolio of 4-5 day long training sessions, addressing many different fields of the ESA expertise. These training sessions are developed and delivered by experts in specific domains. These trainers are usually ESA employees or retirees but may also be specialists from other space organisations, agencies, academic institutions, universities or the space industry. Up to 20 training sessions are organised every year at the ESA Academy's Training and Learning Facility (TLF), located in the ESA Education Training Centre, ESEC-Galaxia, Belgium [2].

In addition, the Training and Learning Programme further supports and promotes interaction with space professional by offering university students:

- sponsorship to participate in international conferences and to present their space related projects,
- support to other space-related learning opportunities coordinated with, or by, ESA partners.

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II. Development of the ESA Academy's Training and Learning Programme

The TLP development began in the second half of 2015, with the aim of complementing the portfolio opportunities offered by the ESA Academy's Hands-on Programme for university students.

In the first six months after the creation of the Training and Learning Programme (TLP), in parallel to designing the overall TLP concept, a first facility called the ESA Academy's Training and Learning Centre (TLC) was developed in ESEC-Redu, Belgium.

In March 2016, the first training session was delivered at the TLC, and it was followed by five other pilot sessions before the end of year. The following years, the portfolio was expanded to allow for the delivery of 13 training session in 2017, 20 in 2018, and 19 sessions are planned for 2019.

In 2018, a new training facility called the ESA Academy's Training and Learning Facility (TLF) was developed in ESEC-Galaxia, Belgium, allowing the participation of more students in each training session (increasing from 24 to 30 students per session) and offering improved livestream and recording functionalities.

Six training sessions have already been livestreamed, allowing additional students to benefit from ESA Academy training sessions.

The portfolio of ESA Academy training sessions is currently composed of over 20 different training sessions listed below in *Table I*:

Table I: List of ESA Academy training sessions

TRAINING SESSION	FIRST DELIVERED	FURTHER DELIVERIES
Gravity-Related Experiments Training Week [b]	Mar-‘16	Jan-‘17 Jan-‘18 Jan-‘19 Jan-‘20[a]
ESA/ELGRA Gravity-Related Research Summer School	Jun-‘16	Jun-‘17 Jun-‘18 Jun-‘19 Jun-‘20[a]
Fly Your Satellite Lessons Learned Workshop [f]	Jul-‘16	
Concurrent Engineering Workshop	Sep-‘16	Mar-‘17 May-‘17 Feb-‘18 May-‘18 Mar-‘19 May-‘19 Jan-‘20[a] May-‘20[a]
Post-Alpbach Summer School Event	Nov-‘16	Nov-‘17 Nov-‘18 Nov-‘19 Nov-‘20[a]
Human Space Physiology Training Course	Jan-‘17	Mar-‘18 Mar-‘19 Oct-‘20[a]
Ladybird Guide to Spacecraft Operations Training Course	Oct-‘16	Sep-‘17[g] May-‘18[c] Sep-‘18[g] Sep-‘19[g] Sep-‘20[a]
Ladybird Guide to Spacecraft Communications Training Course	Feb-’17	Mar-‘18[g] Jul-‘18[d] Feb-‘19[g] Feb-‘20[a]
Introduction to Space Law Training Course	May-‘17	Jun-‘19
Standardisation Training Course	Jun-‘17	Jun-‘18 May-‘19 Sep-‘20[a]
Product Assurance Awareness Training Course	Jun-‘17	May-‘18 June-‘19
Concurrent Engineering Challenge	Sep-‘17	Oct-‘18 Nov-‘19
Rosetta Science Operations Scheduling Legacy Workshop	Oct-‘17	Apr.’19
CubeSats Concurrent Engineering Workshop	Jan-‘18	Jan-‘19 Mar-‘20[a]
CubeSats Hands-on Training Week	Feb-‘18	Sep-‘19
Space Debris Training Course	Apr-‘18	May-‘19[g] Jun-‘20[a]
Earth Observation Satellite Design Training Course	Oct-‘18	Apr-‘20[a]
Space System Engineering Training Course	Nov-‘18	Mar-‘20[a]
Technology Transfer and Innovation Training Course	Nov-‘18	Mar-‘20[a]
Earth Observation Remote Sensing Workshop	Dec-‘18	May-‘20[a]
Fly Your Satellite! Phase D Workshop [e]	Apr-‘19[g]	
ESEO In-Flight Experience Workshop [e]	Aug-‘19	
Clean Space Training Course	Feb-‘20[a]	

[a] Planned but TBC
[b] First edition known as ‘ESA Experiments Hands-on Projects Training Week’; FYT (Fly Your Thesis!), DYT (Drop Your Thesis!), SYT (Spin Your Thesis!) and OYT (Orbit Your Thesis!) students only
[c] Organized for ESEO (European Student Earth Orbiter) students
[d] Organized for ESEO and FYS (Fly Your Satellite!) students
[e] ESEO (European Student Earth Orbiter) students only
[f] FYS (Fly Your Satellite!) students only
[g] With students in livestream

Additional training sessions are constantly under development. For instance, at the time of writing, the Clean Space Training Course is being developed, and it is planned for first delivery in February 2020. Training sessions are usually then repeated annually or biannually.

III. ESA Academy Training Sessions

ESA Academy training sessions last 4 to 5 days and can have different formats, which mainly are:

- **Training courses**: a series of lectures complemented by exercises or a group project.
- **Workshop**: a mix of lectures and hands-on activities.
- **Training week**: a mix of lectures, workshops and/or hands-on activities to provide information and guidance to successfully go through the different phases of an ESA Academy hands-on programme.

Some training sessions are organised in collaboration with other entities. For example: since 2016 the ESA/ELGRA Gravity-Related Research Summer School is organized annually with the European Low Gravity Research Association (ELGRA)

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[[3],[4]] and since 2017 the Human Space Physiology Training Course is conducted with colleagues from the European Astronaut Centre (EAC) [5] and the Concurrent Engineering Challenge with three different universities each year.

A. Training session development

Each ESA Academy training session is developed through a collaboration between the ESA Education Office and ESA technical experts and/or external experts in the field. The development process comprises four Work Packages (Fig. 1):

Design:

Based on the input from the different experts, an overall approach for the training session is defined in this first phase. This is done through the:

- generation of training objectives,
- definition of target student audience,
- definition of training structure,
- definition of training format and delivery method,
- definition of evaluation methodology,
- definition of internal effort, initial planning and trainers.

Development:

This phase translates design decisions into actual training material through the:

- development of lecture plans,
- development of lectures, exercises, group projects, and assessment protocol (if applicable),
- development of the training evaluation form,
- review of the effort required and initial planning,
- a dry-run (1 day) with the objective to verify training objectives, format and sequence of the session, overall content and key messages.

Delivery:

In this phase, the training session is actually delivered. The following sub-tasks are:

- liaison with students and trainers for logistics,
- preparation of final training material,
- conducting the training session.

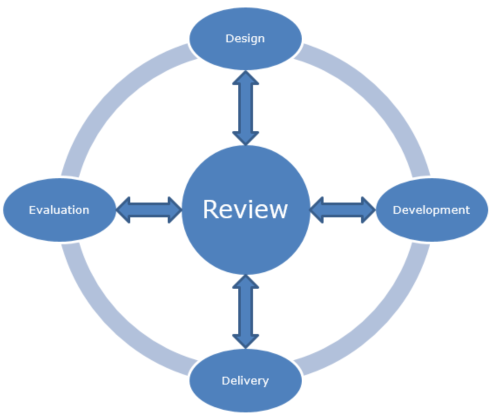

Fig. 1: Overall development process of an ESA Academy training session

Evaluation:

The purpose of this final phase is to verify that the training session has achieved its objectives and identification of strengths and weaknesses and lessons learned. This final phase is done through the:

- analysis of the students, trainers and ESA Education Office feedback,
- update of training format and material as needed.

B. Student application and selection process

In order to participate in an ESA Academy training session, students must fulfil the following criteria at the time of application:

- be aged between 18 and 32 years,
- be a citizen of an ESA Member State, Canada or Slovenia,
- be enrolled as a full-time student in a university (and not graduating before the training session),
- be studying for an engineering or science degree.

For each training session, the profile of the students in terms of level and field of study is tailored to the training content.

Interested students apply via the ESA Education website by filling-in an application form, providing a motivation letter, a CV, a recommendation letter from a university professor or academic supervisor and an official copy of their academic records. Selected students are informed around one month before the training session starts. Their participation is free of charge and ESA provides them with a sponsorship to cover their travel, accommodation and meals.

Most training sessions have open applications, however some specific sessions are offered to students already participating in ESA Academy's hands-on programmes or who are interested in one of these opportunities (see *TABLE I*). In this way the ESA Education Office makes the link between the two pillars of the ESA Academy programme (i.e. the Hands-on Programme and the Training and Learning Programme) and uses its resources and facilities in a synergetic manner.

C. Training session delivery

The training sessions are delivered in the ESA Academy's Training and Learning Facility (TLF) located in the ESA Education Training Centre, ESEC-Galaxia, Belgium. The TLF can accommodate up to 30 students and up to 8 trainers and is both a training room and an educational Concurrent Design Facility (CDF) [6]. The facility contains smart boards, large displays, individual workstations and an audio-video system, which the trainers can control to share their training content and/or to allow students to share their work. In addition, the facility offers recording and livestream functionalities. The general layout of the facility can be seen in Fig. 2.

The training sessions usually last between 4 days (32 hours) and 5 days (40 hours) allowing students to claim ECTS credit(s) from their Universities for their participation.

The number of trainers per training session and their respective contribution depends on the format and topic of the

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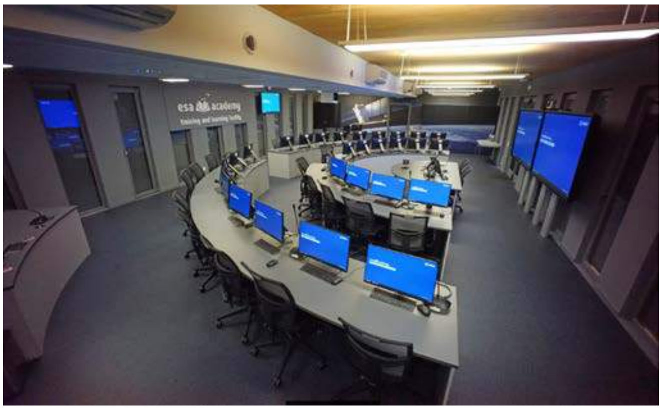

Fig. 2: The ESA Academy's Training and Learning Facility

training session. On average, a training session is delivered by 9 trainers coming from ESA, other space agencies, academic institutions, universities or space industry.

Most of the trainers travel to the ESA Education Training Centre to deliver their content face to face in the TLF, but some lectures are also delivered by videoconference.

For the students following the ESA Academy training sessions via livestream, the lectures are streamed in real time from the TLF. Students are requested to follow most of the sessions live and have a few days to watch the recordings of the other sessions.

For most of the training sessions, the students are evaluated at the end of the week by the trainers through a group exercise or project, or an individual online evaluation questionnaire.

At the end of the training sessions, students go home with a copy of the training content, a certificate of participation and (when applicable) a course transcript, and are asked to fill-in an anonymous online feedback questionnaire.

D. Benefits for the Students

The Training and Learning Programme offers students the chance to complement their university lead education with additional training in subjects that they often are not covered in the normal university curricula.

Furthermore, the TLP offers students the chance to learn from competent space professionals and to benefit from their experience, gaining a transfer of knowledge and experience from the current to the future generation of space professionals.

In addition to the formal benefits of the training sessions, the students also get the chance to network with the trainers, and their peers, forming relationships which may be quite beneficial for them also in their future professional careers. This aspect in particular has proven to be a fundamental part of the programme, and it is often mentioned in the student feedback, as illustrated in the following student quote: "In less than a week, I learnt a lot of new things from many different fields and I had the unique opportunity not only to discuss scientific matters with experts but also to hear their stories and fragments of their lives thanks to their sincere will to transmit to us students their passion and enthusiasm for their work, in which they completely succeeded. Furthermore, I met a lot of students from all over Europe: just in a few days, they passed from being strangers to esteemed colleagues and, more than all, good friends. I am happy to have gained so much from that week, not only in terms of knowledge but also in terms of personal growth, special connections and friendships."

E. Challenges

Throughout the development and growth of the TLP, a number of challenges were met, including the following, which may be of interest to others developing training sessions:

- identification of relevant topics to create a portfolio of training opportunities to complement what is taught at university,
- defining standard and corporate formats for the training sessions including specific procedures, documents, templates, vocabulary, …
- finding experts (and backups) interested in sharing their knowledge and know-how with the students, and who are available to develop and deliver training content (both in terms of time and skill)
- adapting the content of the training session to the level and background of the students and/or ensuring the correct study level of students is identified for the training session,
- ensuring a coherent and consistent training content to offer a complete overview of the topic to the participating students,
- efficiently promoting the programme and training sessions opportunities to reach students in all ESA Member States, Canada and Slovenia,
- managing high or low number of applications,
- selecting, with a fair and consistent selection process, a balanced group of students taking into account nationality, gender, level and field of study, …
- developing livestream activities and explore possible e-learning opportunities to increase the number of students benefitting from the existing programme,
- scheduling an annual programme to ensure a minimum number of training sessions and repeatability of the different topics,
- implementing intellectual properties rules and data protection policies,
- dealing with logistics and administrative tasks related to the organisation of about 2 training sessions per month involving a large number of participants coming from worldwide locations,
- maintaining and upgrading the training facility to ensure smooth training delivery,
- …

Last but not least, it is interesting to recall that the Training and Learning Programme is a "living" entity, built upon a dynamical approach, which constantly evolves to adapt to internal factors (from trainers and participating students) and external (new technologies, new topics identified to be brought to the attention of the students): as it developed, key improvements were made, taking also into account students' and trainers' feedback, and profiting from the progressively more and more enriched experience of the ESA Education staff involved.

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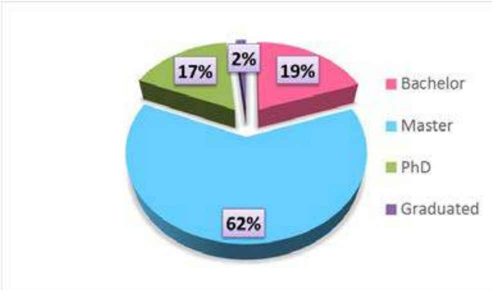

Fig. 4: Level of study of participating students

IV. Feedback and Statistics

1287 Bachelor, Master, PhD students and young graduates (the latter mostly from the Post-Alpbach Summer School Events), of which around 30% were female, have participated in the 52 ESA Academy training sessions delivered between March 2016 and June 2019 (Fig. 3).

The students came from 27 different countries (students from non ESA Member States only accepted for Post-Alpbach Summer School Events) and 290 different universities from around the world (Fig. 4), with a wide variety of backgrounds in science and engineering including aerospace, mechanical, electrical and telecommunications engineering, physics and astrophysics, space science, and medicine.

Through the livestreamed sessions, 81 additional students were able to follow some ESA Academy training sessions online.

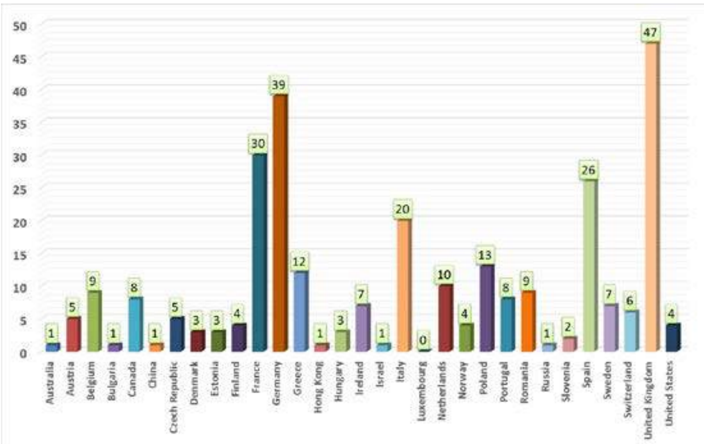

Fig. 3: Number of universities of participating students per country

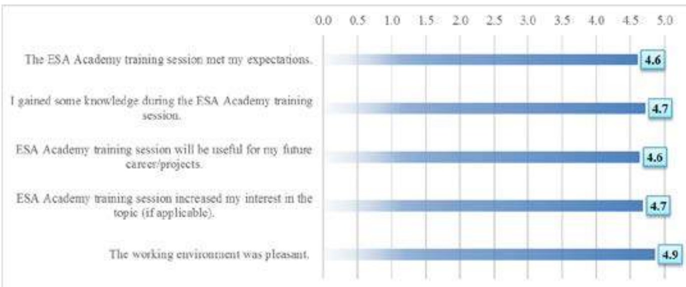

Fig. 5: Students feedback after their participation in an ESA Academy training session (1 = totally disagree, 5 = totally agree).

To continually improve the ESA Academy's Training and Learning Programme, the students are asked to provide anonymous feedback and impressions after each training session. As shown in Fig. 5, displaying the average answer given by the participating students over 52 training sessions, the training sessions are clearly perceived as beneficial for the students' education and future career.

V. Further Development and Challenges

In the coming years, more ESA Academy training sessions will be developed to complement the TLP portfolio and to cover additional fields of the ESA expertise.

Existing training sessions will continue to be updated after each edition, to ensure the quality and accuracy of the content and to ensure that it is delivered in the most effective manner to the students. As the job market is changing and students have to develop their "21st century skills" to stay competitive, ESA Education Office needs to identify new "space" skills and take them into account when developing new opportunities.

To increase the number of opportunities for the University students, the number of training sessions offered annually in the TLF will probably be increased in the coming years, as well as the number of livestreamed sessions. In addition, ESA Education Office is considering to develop a few online courses based on the content of existing ESA Academy training sessions and to offer them on a dedicated e-learning platform.

Acknowledgments

The Training and Learning Programme is only possible thanks to collaborations with many ESA departments and external organisations, and relies on the support of their experts who develop and deliver the training sessions; the ESA Education Office would like to thank them for their contributions.

Furthermore, the authors would like to thank all their colleagues of the ESA Education team, because their competence and dedication are key to ensure University students can get the best possible benefit from their participation in the ESA Academy's Training and Learning Programme.

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ESA and NAROM student rocket program Fly a Rocket!

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***Abstract*— The Fly a Rocket! programme is a hands-on programme which gives students the chance to learn more about space science and technology, and to launch their very own student rocket from the Andøya Space Center in Northern Norway. The programme was initiated as an ESA Academy program in collaboration with the Norwegian Center for Space Related Education (NAROM) and the Norwegian Space Agency (NSA) as a pilot in 2017 [1]. The aim was to give students in the early years of higher education the possibility to work on a real rocket project and learn about space physics and space engineering and thereby to inspire and motivate the students to consider careers and further study in space and space related disciplines. The pilot cycle was a huge success hence a second cycle was initiated in the fall of 2018, and the rocket launch campaign was in the spring of 2019. This paper will present the ESA and NAROM student rocket program Fly a Rocket! and its objectives together with the experiences and lessons learned from the two cycles of program.**

Keywords— Student rocket, launch campaign, space physics, education, hands-on, fly-a-rocket

I. Introduction

The ESA Education Office has a long experience inspiring young people with their portfolio of activities, both for Primary and Secondary school level and for University students. Maybe the two best known are the REXUS/BEXUS programme for university students and the CanSat competition for high school students. Previously there had been a limited offer for students that had just started their university studies, however, with the Fly a Rocket! student rocket program it is possible to fill this gap. NAROM has since 2000 had a student rocket program that fits this gap very well to give students that have recently started on their university studies an introduction to a “real” rocket project.

The program is a collaboration between ESA, NAROM and the NSA, and all the three parties provided funding for the pilot and subsequent cycle.

The Fly a Rocket! Programme [2] offers a unique opportunity aimed at bachelor’s level students early in their studies and will give them an introduction into space science and technology. While an understanding of some higher-level mathematics is required, candidates need not necessarily be from an aerospace background, however they should show, and demonstrate a strong interest in the space industry, space science or technology.

The programme is divided into three parts, in addition to the application process, which are described further in the next section. Students take part in an online pre-course, learning about rocket engines and dynamics, satellite orbits and details about NAROM’s student rocket remotely. After the pre-course students are invited to participate in their own launch campaign at Andøya Space Center (ASC) in Northern Norway, where they will, as part of a team, build, verify and launch their own student rocket! After the launch at Andøya, participants will work together to analyse the results of the flight and to produce a final report to deliver to ESA.

II. The Programme

Through the student’s participation in the programme the students go through exactly the same procedures as in a professional scientific sounding rocket campaign at ASC, but on a more condensed time scale. The students gain experience on how to work as a team with other students from several different countries on a real rocket project and build experiments using different kinds of digital and analogue sensors. The students do all the work, including manning all stations during the countdown before launch, with supervision from NAROM and ASC professionals.

During the student rocket campaign, the students’ practical work is mixed with lectures from experts. The lectures cover topics such as rocket physics, space physics, satellite engineering, and telecommunication. Following campaign the students will be able to set up a model in rocket simulation software, describe the principle of the sensors on-board the rocket and analyse and interpret the data from the sensors. In addition, during the course, the students will make, and release two stratospheric weather balloons used for monitoring the state of the atmosphere prior to launching their rocket.

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A. Programme objectives

A very important part of the Fly a Rocket! programme is a practical approach. From experience, we find that mixing some lectures/theory in the classroom with practical work works great and is very encouraging for the students involved. This is also important for showing the students how an actual scientific project is, and at least the campaign period is very similar to an actual, “real” rocket campaign in every aspect, only condensed.

Students who take part in the student rocket programme will gain experience in how to:

- Reproduce a scientific project: scientific objective, building and testing instrumentation, retrieve telemetry data, analysis, and conclusions
- Work on a real rocket project as a team and interact with industry experts and other students from several different nations.
- Build experiments using different kind of digital and analogue sensors, and to learn how these works
- Be a part of a student rocket operation at Andøya Space Center
- Analyse scientific and technical data and compare this with models
- Set up a model in a rocket simulation software and perform several simulations and analysis

In addition, students will also learn about:

- How a rocket engine works using solid, liquid or hybrid propulsion technology.
- Basic rocket theory
- Rocket aerodynamics and stability – The physics behind a sounding rocket and know the forces acting on a rocket.
- The use of rockets, balloons and ground based instruments as a technology platform to study processes in the atmosphere.
- Sensors and basic electronics – A/D conversion, Encoder/Decoder, Telemetry, radio communication
- Describe the principle of the sensors on-board the rocket and weather balloon and be able to analyse and interpret the data from the sensors.
- Basic understanding of orbital mechanics and the principle and use of satellite navigation

International cooperation across different languages and cultures is also an important part of the learning outcome of the program. In addition, the student rocket programme is perfect for getting experience and learning abilities such as working in groups, communication, interdisciplinary communication, presentations and reports.

B. Application and selection process

Over 200 applicants applied for the total of 24 places for the 2018/2019 cycle. The selected students represented 14 ESA member states and Canada. The application from the students consisted of a single document where the student would describe his/her motivation for joining the programme, what outreach would be done if accepted, a tie-breaker with a suggestion of the name of the rocket, and a technical task were the student had to suggest an additional payload on the rocket. The selection process was done by ESA.

Figure 1 The Fly-a-Rocket! Students 2018/19

C. Online pre-course

For the programme, students from all fields are invited to apply. Since the students are not necessarily from a closely related subject, an online pre-course was developed for the pilot cycle of the programme and further developed for the second cycle of the programme. The pre-course was made to bring all participating students to a given academic level to make it easier for everyone at the campaign period to start with the same background information. For some students already at a high academic level in the related subjects the online pre-course was expected to be quite easy and for others it would probably be more difficult and demand more work/time to complete. The pre-course consisted of two parts: an online portal openly available for the public [3], and two exercises based on the content of the online portal that the students needed to write a report of and hand in to NAROM. Answers to both exercises needed to be delivered to NAROM to be invited to the rocket campaign at Andøya. All students got individual feedback on both their reports.

The subjects for the second cycle pre-course was:

- Rocket Engines
  - The rocket principle
  - The rocket equation
  - Total impulse
  - Nozzle

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- Rocket Motor Efficiency
- The Engine types: solid, liquid and hybrid, ion

- Rocket Dynamics
  - Aerodynamics and forces acting on the rocket
  - Simulating a rocket launch
- Satellite orbits
  - Kepler's laws
  - Introduction to the six basic parameters
  - Orbit Equations in a plane
  - Examples of Orbits
- NAROM Student Rocket
  - Encoder, transmitter and the sensors
  - Encoder Frame
  - Mongoose 98 student rocket

D. Rocket campaign

The most important part of the project is the student rocket launch campaign at Andøya Space Center. The students arrive on day 0, and over the next five days the students will have introductory lectures for the week and group work to prepare for the rocket launch. The NAROM student rocket is a 2.7 meter long Mongoose 98 sounding rocket with a carbon fiber body with an apogee of approx. 8.5 km altitude and a flight time of 90 seconds. The rocket is spin stabilized and is not despun during flight. The impact area is at sea, and there is no recovery attempted.

The students are divided in to four teams which have specific responsibilities for preparations prior to the rocket launch as explained below:

1. Payload team: make sensor cards, make custom cables in the rocket, install all sensors in the rocket. Prepare the rocket itself before launch and test it in collaboration with the telemetry group
2. Telemetry team: Setting up all the telemetry equipment and decoders and test this prior to launch receiving signal from the rocket in collaboration with the payload group. Do the first pre-analysis of the flight data and present this at the post-flight meeting
3. Sensor Experiment team: make several different sensor boards and discuss with the payload group where to place the specific sensor boards in the rocket. Develop sensor digital-to-analogue conversion equations and hand them over to the telemetry group for use in the decoder setup. The sensor experiment group also build two PTU sensor packages and release these under two weather balloons prior to the rocket launch, analyse and present the weather balloon data.
4. GPS team: Make, configure and test GPS sensor card including data cabling made in collaboration with the sensor experiment section and perform macro scale rocket simulations (position (trajectory), velocity, acceleration and other derived parameters during flight)

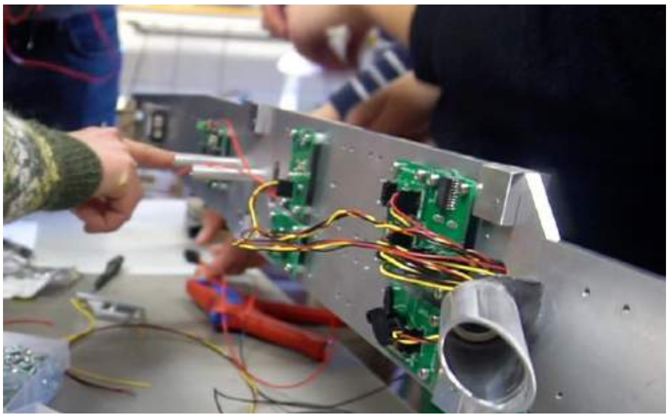

Figure 2 Sensors in the rocket

Together, these team go through all the preparations the same as before a large scale rocket campaign, but again on a more condensed scale. It was emphasized to the students that all the students in the teams were part of one large group and thus were encouraged to collaborate to finish the rocket in time prior to the launch window. The students do all the work of the campaign but are assisted by professionals from NAROM and ASC.

During the nominally 60 minutes long countdown the students take an active part, including filling the positions as Head of Operation, Payload Manager, Pad Supervisor, Principal Investigator and all other positions, but again with the assistance/help from NAROM and ASC.

After launch, the students are again divided into groups as for the pre-launch work and analyze the rocket data. On the last day of the campaign, the day after launch, the students have presentations for each other and NAROM/ASC to present the data analysis they have completed the day before.

E. Student pilot cycle end report

After the launch campaign, the students start work on a single, large project report which they all have to contribute on with one student taking the lead on the work.

F. Improvements from the pilot cycle

Though the pilot cycle student feedback and evaluation from ESA and NAROM were very positive, it showed some parts that could need improvements, which is discussed in more detailed in this section.

The first assignment during the online pre-course phase, which focused mostly on rocket physics, was a success and all students performed well. However, the second assignment, which focused mostly on orbital mechanics, was a bit harder by design, and many of the students performed below par on their assignments. The assignment has a subject which most students do not know very well, and they were meant to collaborate with each other on a social media group to solve this assignment. The

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students did not use this opportunity, and hence it quickly got difficult to answer all the questions on the assignment since they did not help each other. For the 2018/2019 cycle, NAROM were not a part of the social media group to help to try to make a "friendlier" environment. This and a mix of students that worked well together helped very much and the second assignment on this cycle was a huge success, with all students performing very well. Working together on the social media group also help to create a group feeling even before they met each other physically for the first time at Andøya during the launch campaign.

During the group work at the launch campaign during the pilot cycle, the students were divided into five distinct group that collaborated little with each other. During the 2018/2019 the students were part of one large group with many areas of responsibility. The students were expected to help out wherever help was needed. To make it easier for the students to get an overview of where their assistance or help was needed during the rocket launch preparations in order to meet the campaign deadline, a check-list of tasks was printed and hung on a central wall in the laboratory where the students worked on the rocket and sensors. Each student marked a task as "started" when starting a task and as "finished" when completed the task. In that way it was easy for everybody to follow the progress. The workload was also bigger with more sensors flown, so it was essential that all students helped each other to complete all the tasks before the deadline. This means that all students took an active role with working with the preparations for the launch, which really helped with their understanding on a detailed level and on a system level.

Another initiative that helped to give the students a feeling that they were part of a real rocket or space mission campaign is the introduction of a verification document that should be filled for every sensor going to be launched in the rocket. The verification document stated the type of sensor, test method and -results and the wanted spot to be placed in the rocket together with signatures of both the student that build and tested the sensor board and of a representative from the payload team stating approval of this specific sensor board.

III. After the campaign

An extensive survey was done by ESA after the end of the pilot cycle, which showed that the students was very satisfied. Some improvements were noted from the survey and by ESA and NAROM throughout the cycle. Some of the results are discussed in [4]. Another survey was done for the 2018/2019 cycle also showing that students was very satisfied. Suggestions for improvement from the survey has been noted and to be taken into account in the case of any future Fly a Rocket! Programme.

Many of the student participants choose to present their participation and flight results at international conferences, and nearly all completed some kind of outreach (as per their application), to promote space, science and STEM in general.

Figure 3 3, 2, 1, 0, ... Lift off

IV. Conclusion

The second cycle of the Fly a Rocket! ESA Academy program in collaboration with the Norwegian Center for Space Related Education (NAROM) and the Norwegian Space Agency (NSA) was initiated in the fall of 2018, and the rocket launch campaign was in the spring of 2019. The Fly a Rocket! programme which is a hands-on programme giving students the chance to learn more about space science and technology, and to launch their very own student rocket from the Andøya Space Center in Northern Norway was a huge success and had some new initiatives compared to the pilot cycle which enhanced the students learning further during the pre-course and their sense of working in a group with other students on a real rocket project. The new initiatives included a more collaborative setup both during the online pre-course and during the rocket launch campaign.

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MELT: Monitoring iceberg calving using Synthetic Aperture Radar

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***Abstract*—The movement of glaciers in remote regions of Greenland and Antarctica have been tracked using images captured by the European Space Agency (ESA) Sentinel-1 mission. The mission is composed of two satellites equipped with C-band (4-8 GHz) synthetic-aperture radar instruments that allow for the collection of high-resolution images and data in all weather conditions. Using imaging provided by the Centre for Polar Observation and Modelling (CPOM), and in collaboration with the Institute for Research in Schools (IRIS), the movement of two key outlet glaciers on the Antarctic and Greenland ice sheets (Pine Island and Petermann glaciers, respectively) has been monitored in near real time. In addition to this, key glaciological features, such as ice speed and supra-glacial lakes have been observed and monitored.**

Keywords—Greenland; Antarctic; glaceology; glaciers; calving; climate change

I. Introduction

The continental glaciers of Greenland and Antarctica provide one of the key outlets for the mass of water accumulated on these landmasses during winter months. Glaciers are formed by the steady accumulation of snow which, over time, is compacted to form ice and begins to flow outwards and downwards under the pressure of its own weight [1]. A major part of the life cycle of a glacier is iceberg break-off, or "calving". Calving, along with melting and surface evaporation, is the main sources of glacial ablation and gives a strong indication of the health and stability of the glacier [2]. Studies of glaciers and the relationship between global temperature, glacial melting and rising sea levels give indication of how strong and long-lasting any effects of climate change might be [3].

The icebergs that are calved from glaciers are an important source of fresh water in salty seas [4], can provide a valuable habitat to marine life [5-6] and pose a significant threat to shipping [7]. As such, it is important that the location and timing of iceberg calving, as well as the movement of icebergs away from calving fronts is monitored.

Historically, the tracking of glaciers was achieved by comparison of optical images obtained from satellites. However, the acquisition of optical images was limited by the necessity for daylight and favourable weather conditions [8]. More recently, the use of synthetic aperture radar (SAR) images has become standard. The launch by The European Space Agency (ESA) of the Sentinel 1-a and 1-b satellites, in April 2014 and April 2016, respectively, allow many key ice margin areas to be systematically monitored every 6 to 12 days. This novel dataset allows the periodic movement of glaciers as well as movement over short timescales to be monitored. Here, we present a comparison of the movements of the Petermann Glacier in Greenland and the Pine Island Glacier in Antarctica between 2015-2018, made using the Sentinel SAR archive.

II. Sentinel-1 Near Real Time Ice Velocity

All data for this project has been accessed via the Centre for Polar Observation and Modelling (CPOM) outlet glacier velocity service [9]. Images were recorded by Sentinel-1, a two-satellite constellation which carries an advanced all-weather imaging radar. Sentinel-1a was the first satellite to be launched as part of Europe's Copernicus programme, and has delivered a wealth of data and imagery since it was launched in April 2014. During its first year of operations, the short 12-day imaging repeat period and large spatial coverage delivered an invaluable new resource which revolutionized the ability to monitor change in speed of the ice streams on the Greenland and Antarctic Ice Sheets. Europe's satellite monitoring capability continued to be improved even further with the launch of Sentinel-1b in 2016, and combined, both satellites provide the capability to image the earth every 6 days.

A. *Study Areas*

Antarctica is surrounded by ice shelves and the floating ice tongues of glaciers. With a total area of more than 1.5 million square kilometers, this floating ice represents an area of approximately equal size to the entire Greenland Ice Sheet [10]. The main mechanism for mass loss has historically been iceberg calving but warming oceans have meant that melting is becoming increasingly significant [10]. However, the in-land ice of the Greenland ice sheet contains the equivalent of 7.2m of sea level rise making the future of the mammoth sheet one of the largest and most complicated issues facing environmental policy in the coming years [10-11].

In order to compare northern and southern hemisphere glaciers, one glacier was chosen for study from each of the three glaciers on Greenland and Antarctica for which data are provided on the CPOM server.

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B. Data and Methodology

Ice velocity was mapped using single look complex (SLC) synthetic aperture radar images acquired in the interferometric wide swath (IW) mode from the Sentinel-1a and Sentinel-1b satellites. Each satellite has a repeat cycle of 12 days and 180 degrees orbital phasing difference, resulting in a revisit time of 6 days over the same area after the Sentinel-1b launch. The Sentinel SAR instruments operate at c-band, with a centre frequency of 5.405 GHz, corresponding to a wavelength of 5.55 cm. The IW mode has a 250 km swath and spatial resolution of 5 m in ground range and 20 m in azimuth. It has burst synchronization for interferometry and acquires data in three sub-swaths, each containing a series of bursts, which are acquired using the Terrain Observation with Progressive Scans SAR (TOPSAR) imaging technique [12].

Images were processed using QGIS 2.4.0-Chugiak software. The software was used to generate shapefiles that could include annotations of images as well as positional information on key features, such as calving fronts. Comparisons of images taken on different days allowed for the rate and change position of calving fronts to be monitored (Figure 1).

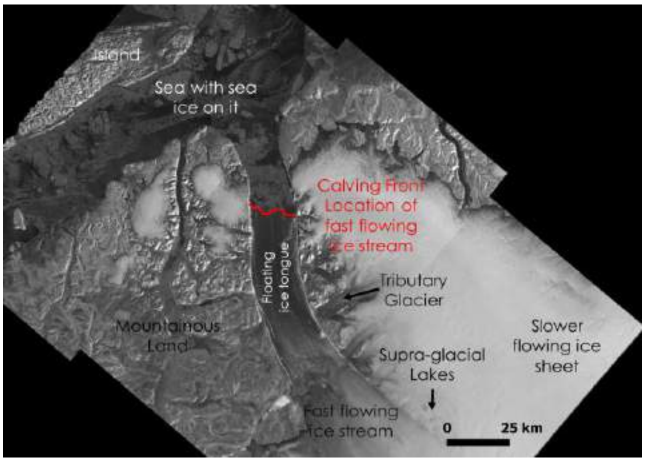

Figure 1: An example image of the Petermann Glacier, with key features labelled. Image Credit: A.E. Hogg, CPOM, Uni. Leeds, ESA and S. Pengelly, CSMS.

III. Results and Discussion

A. Petermann Glacier (PG), Greenland

Petermann Glacier (PG) is one of the major outlet glaciers in northern Greenland and drains roughly 4% of the Greenland ice sheet [13]. It has the second largest floating ice tongue in Greenland and so loses most of its mass (80%) by bottom melting [14]. However, significant calving events in 2010 and 2012 produced tabular icebergs of 253 km^2 and 147 km^2 respectively, reducing the extent of the floating ice tongue by approximately a third. Both calving events have been correlated to increased flow rates of the glacier [15].

Initially, the calving front location for PG was tracked between December 2016 and December 2017. In the ~4 months between 6th January and 31st March, the calving front had advanced by an average of 462m, approximately 7.5m per day. It was noteworthy that different sections of the calving front moved at different rates, the western extreme having moved 379m further that the eastern edge. Using the average speed of the calving front from the first four months of the year, an approximate calving front position for December 2017 was predicted. Correlation between calculated and actual positions was reasonable for the western and central parts of PG but the eastern edge showed a significant loss of ice (Figure 2). This could not be contributed to a single calving event but was the result of a more gradual ablation of the calving front.

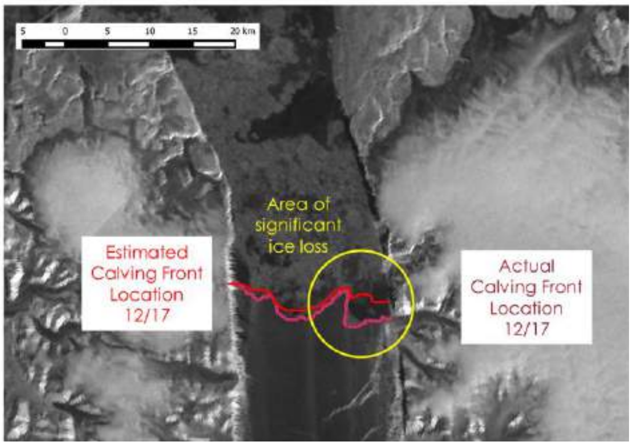

Figure 2: Difference in the calculated calving front (red) and actual calving front (maroon) for December 2017, showing an area of significant ice loss at the eastern edge of Petermann Glacier. Image Credit: A.E. Hogg, CPOM, Uni. Leeds, ESA and S. Pengelly, CSMS.

Using images of the glacier at the same time each year, the forward progression of the glacier over longer time periods could be tracked. By comparing the shapefiles generated on images from February 2015 to February 2018 (the tenure of the Sentinel-1 satellite at the time of analysis) the glacier was calculated to be moving at a forward rate of 1.15 kilometers per year (Figure 3).

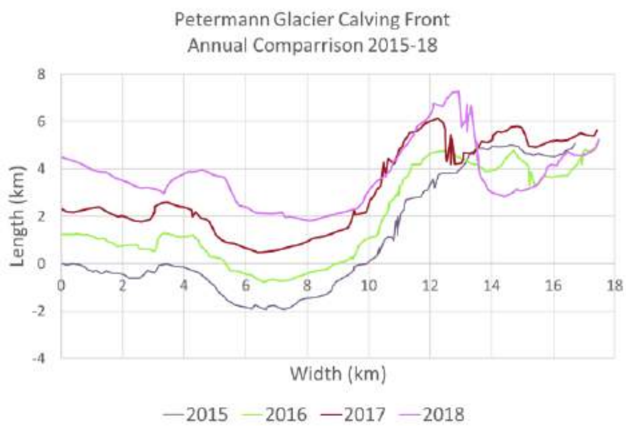

Figure 3: Plot of calving front locations (CFLs) for the month of February 2015-2018. A comparison of locations shows a steady flow equating to an average of 1.15km/y. CFLs clearly show the differing flow rates of the different sections of the glacier; the western extreme flows significantly faster than the eastern edge which in turn is faster than the centre.

As had previously been seen, the western edge of the glacier was found to move at the fastest and at a most constant rate. The central section of the glacier moved at a slower and less regular

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rate. The glacier moved slowest and with the most erratic rate at the eastern edge, especially in 2018 when a large amount of ice was lost from this section. It is speculated that the reason for this discrepancy in movement is the contribution of tributary glaciers which may disrupt the flow and stability of PG's eastern edge [12].

B. Pine Island Glacier (PIG), Antartica

The Pine Island Glacier currently experiences the largest negative mass balance of all Antarctic glaciers and so is the biggest single contributor to modern sea-level rise [16]. Recent evidence of a volcanic geothermal heat source beneath the Pine Island ice shelf and glacier [17] may go some way to explaining the high flow rate of the glacier; since 2008, the ice stream has accelerated and is now responsible for about 25% of Antarctica's ice loss [18].

The first available image of the calving front on PIG came from the 14th June 2017 and showed one feature of particular interest, a crevasse extending approximate 17km across the face of the glacier and approximately 8km behind the calving front (Figure 4).

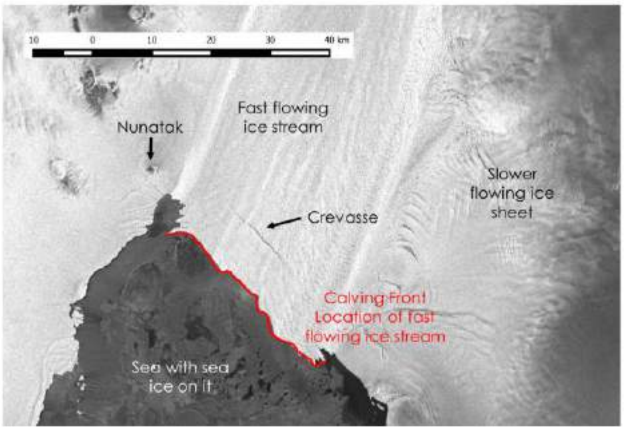


Figure 4: The first available image of the Pine Island CFL showing a crevasse developing approximately 8km behind the CFL. Image Credit: A.E. Hogg, CPOM, Uni. Leeds, ESA and A. Baker, CSMS.

By September 2017, the crevasse had extended across the full width of the advancing glacier, calving a section of ice approximately 300km^2 in area that, over the following weeks, was rapidly broken down into smaller chunks of ice (Figure 5).

The movement of the crevasse gave a useful way of measuring the speed of the glacier, without having to rely on taking measurements from the fragile calving front. Between 14th June and 29th December 2017, the crevasse (which eventually developed into the calving front) progressed an average of 1.56km, a rate of just over 7 meters per day. The rate of movement was relatively constant, showing no significant post-calving acceleration.

IV. Conclusions

All processed images and shapefiles generated as part of this project have been uploaded to the IRIS data server and are available to other scientists through the CPOM network.

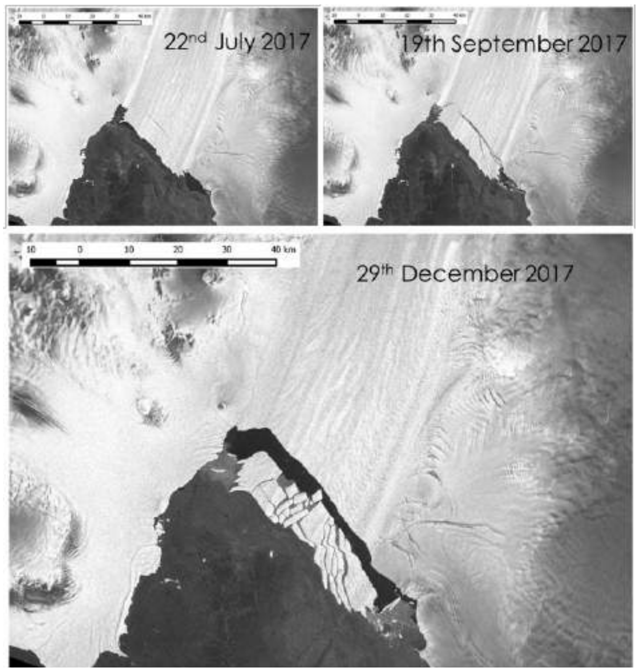
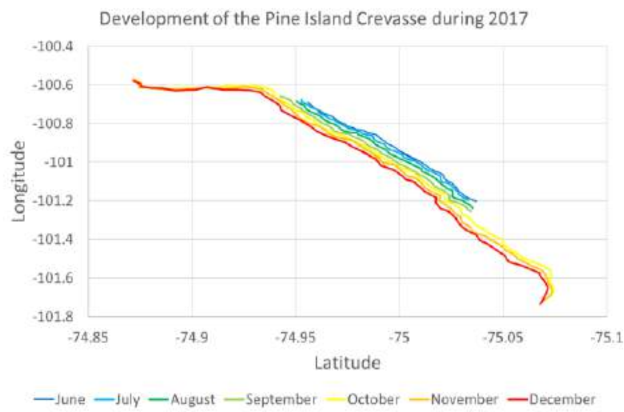


Figure 5: (above) The calving and subsequent breaking up of a ~300km^2 section of PIG between June-December 2017. Image Credit: A.E. Hogg, CPOM, Uni. Leeds, ESA and A. Baker, CSMS. (below) Development of the PIG crevasse; October 2017 represents the first data point post calving and thus the establishment of the new CFL.



SAR images recorded by the Sentinel-1 satellite constellation and distributed by the Centre for Polar Observation and Monitoring offer a fascinating insight into some of the world's biggest and fastest flowing ice streams. The two glaciers studied here have displayed very different behaviours over the brief duration of this project but are of ongoing interest to glaciologists.

The use of SAR for near-real time study of glaciers is of vital importance to monitoring their behaviours. It is hoped that by better understanding the dynamics of glaciers, calving and glacial melting, scientists may predict how the Earth's delicate icecaps may respond to its rapidly changing climate.

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The COSPAR Capacity Building Initiative

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Abstract— The Capacity Building Programme (CBP) is considered today one of the flagships of COSPAR (Committee on Space Research) activities. The programme started in 2001 as a tentative project designed to widen expertise in space sciences and promote the use of data archives from space missions in developing countries, as a way to foster in those regions of the world high quality scientific activities. In the past 19 years a total of 35 COSPAR workshops have been held, involving more than 1000 advanced students and young researchers in 21 different developing countries. Participants have learnt in a highly practical manner how to analyse data from diverse space missions, covering practically all Space Science disciplines, from Astronomy to Earth Observation, from Solar Physics to Planetary Sciences, including Ionosphere, Magnetospheric sciences and even Planetary Crystallography. A key to the success of the CBP has been the strong and selfless engagement of internationally high ranked scientists as well as of the space agencies, ESA, NASA and JAXA. I will discuss in this presentation the history and current status of the Programme, but emphasise the changes we are introducing to make it better, more efficient and wider in scope.

Space Sciences; Capacity Building; Space Educational Activities; COSPAR

I. Introduction

The Committee on Space Research (COSPAR) gathers national and international science academies and institutions of 46 countries, contributing to promote space sciences activities.

The Capacity Building Programme (CBP) was initiated by a COSPAR Associate, Professor Peter Willmore (Univ. of Birmingham) at the beginning of the millennium with the following purposes:

- to increment the knowledge and usage of space data public archives together with corresponding tools in developing countries. This should extend the research horizons in those countries and make

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sure that local scientists are aware of the opportunities brought by those data and tools, publicly available,

- to instruct practically the students in the practical usage of archives and associated software,
- to promote professional bonds between the CB workshop participants and experienced scientists acting as teachers and supervisors, reducing the inherent isolation suffered by scientists in developing countries.

With these purposes a program of highly practical scientific regional workshops was conceived, with a duration of approximately two weeks, which are based on space science missions offering free access to their data and reduction and analysis tools. A demonstrated interest in the scientific area in the region where the workshops take place is one of the prerequisites, since the basic idea is that the workshop participants make use of the gained knowledge in their later scientific career as a contribution to that country / region.

II. Basic (Space) Sciences in developing countries

There is a strong correlation between scientific productivity and present and future economic development of a country. There are even indicators that countries focusing their scientific activity in applied sectors grow slower than those doing it in basic areas [1]. It is also common sense that applied sciences research needs a basic sciences substrate: “There is no applied science without a systematic set of ‘pure’ scientific knowledge behind, and almost all ‘pure’ sciences are continuously applied for solving concrete problems” [2].

Beyond these considerations we value the basic concept that science knowledge shouldn’t have any ownership, but has to be a common good of human kind, distributed in all directions in this uneven world.

Several factors inhibit development of basic sciences in developing countries. Fundamental space sciences particularly suffer due to high cost of experiments. Mitigating this difficulty is the fact that we live in the era of information distribution in which all kinds of data and knowledge are freely offered. The development of open source code and tools offered through web services give a new dimension to the accessibility of science data. Particularly in astrophysics, the concept of public observatory, developed in the 20th century, has favored the development of a culture of open access to science data. As of today, any large astrophysical space mission is expected to eventually disseminate not only its results but all of its scientific data in open public archives. The archives have become a fundamental source of scientific research. The highest point in this development has been the initiative of the Virtual Observatory (VO) [3], which interconnects all the main astrophysical archives (both from space and ground observatories), after a rapid process of standardisation has taken place. This is maximising usage of the archives, facilitating user access to data and visualisation and analysis tools.

This example of openness and active scientific data dissemination is followed more and more in other disciplines. Planetary and solar physics data for instance have profited from sharing resources with astrophysics in the archive development sector of the large space agencies.

III. Archives and analysis tools

A large number of modern data archives do exist today, in most cases every single one associated to a space mission, an experiment, or a telescope. The European Space Agency (ESA) develops and maintains them in its European Space Astronomy Centre (ESAC) in Spain. Their suite of archives comprises data from astronomy, planetary and solar missions of most diverse types [4]. Enormous amounts of data are presented in different stages of reduction, from raw to fully processed, going far beyond a simple offer of data collections. Much effort is put into helping and boosting the possible exploitation of all the data contained in the archives, with the aim of maximising scientific return, i.e., to reach the largest possible number of users, independently of nationality or professional affiliation.

While the archives generally offer calibrated and processed data to different levels with a standard reduction, the maximal extraction of the science contained is often only possible through the usage of interactive data analysis tools, capable of optimising the signal to noise ratio according to the specific scientific purpose. Most large projects offer these kinds of analysis tools publicly with the same aim as

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the one mentioned for the archives: maximisation of scientific return [5].

The COSPAR Capacity Building workshops have been structured around these two elements: public archives and freely available analysis tools. The first workshop of the Programme was held in 2001 at the National Institute of Space Research (INPE) in Sao José dos Campos, Brazil, devoted to X-ray Astrophysics, and based on the space missions Chandra (NASA) and XMM-Newton (ESA). Both missions were already providing in 2001 advanced scientific archives with a reasonable amount of public data and data analysis software freely distributed[a]. This workshop has been organised eight times in several countries (Brazil, India, South-Africa, Egypt, Argentina, China and Mexico), representing more than 20% of all CB workshops.

While publicly accessible resources make it possible to perform scientific research at a high level at any location in the world, users come mainly from developed countries for several reasons. The two most important causes are the lack of knowledge about the existence of publicly accessible resources in developing countries, and a clear deficit in developing regions in space sciences, since related disciplines do not belong to the traditional local research areas.

A clear impulse for profiting scientifically in developing countries from those resources could be given, therefore, through an educational program, trying to revert this situation. So the Capacity Building Programme was born, sustained by COSPAR [6], with the main aim of encouraging scientists from developing regions to make use of scientific space data and tools.

IV. Broadening of the Programme

After the first two workshops in X-ray astronomy, the CBP started to broaden its range, until today most of, if not all, the space science disciplines are covered.

In the last eighteen years a total of 35 workshops have taken place, covering all areas of astronomy (gamma, X-ray, infrared, optical and ultraviolet), along with planetary sciences, magnetospheric physics, Sun-Earth interactions, diverse Earth observation fields, space weather and even crystallography in space. They have taken place in 21 different developing countries. The initial frequency of an annual workshop has been tripled and more than 1000 students from developing countries have participated so far.

V. Learning needs and characteristics of the CBP workshops

The typical target of the workshops is a young scientist, PhD or Master student, or recently finished with his/her studies. The learning needs start often with the specific type of science in areas not mastered by the participants. These may simply be not studied by existing researchers in the region, or lie in a different part of the electromagnetic spectrum to those they have been exposed to. The instruments on board space missions are generally less known or totally unknown, as is often true with their data characteristics. Also, the usage of science archives as fundamental source for research is often a novelty. In many cases, the analysis techniques and obviously the mission specific analysis tools, as key for the future work, are the central elements of the practical work during the workshops. Of course, all these elements depend on the specificities of the area, which can be highly different, as it can be assumed from the broadness of the Programme. In the general case a workshop's agenda includes lectures on all the topics mentioned above, but the central element of it is the individual project of the student, who will use the new knowledge and techniques learnt to extract science from the data (s)he is going to work with, be this alone or in teams. All these elements together define a general duration of a workshop of two weeks, as a compromise between the learning necessities and the real possibilities to go through a small scientific project under the active supervision of the international experts, who are at the same time lecturers of the workshop.

The average CB workshop has 25-35 participants. Around 10 lecturers / project supervisors are needed to cover the diverse topics and to ensure active and effective supervision. Participants are recruited internationally by scientists and data analysis specialists in the area of the workshop. The projects can be carried out individually or in teams;

[a] Eighteen years later both missions are alive and extremely productive. A lot more data than in those days are available!

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appropriate supervisors are chosen and correspond to the specific project. Each projecthas one or two supervisors. The workshops end with an individual presentation by every student (oral talk or poster) in which the comprehension of the methodology and the ability to work with data and specific area tools have to be demonstrated.

One fundamental element in the COSPAR CBP philosophy is that students and lecturers reside in the same hotel during the entire duration of the workshop, sharing also all meals. The direct contact with international specialists is of paramount importance for students from developing countries in their scientific careers.

VI. THE CBP ASSOCIATED FELLOWSHIP

In 2010 we complemented the Programme with an associated fellowship. Fellowships are open to young scientists who have been participants at one of the COSPAR Capacity Building workshops. The objective is to enable participants to build on skills gained during the workshops. Fellowships consist of visits of 2-4 weeks duration for the purpose of carrying out joint research in laboratories that collaborate with COSPAR in organizing the fellowship program.

VII. NUMBERS AND RESULTS

During the 19 years of the CBP, COSPAR has held 35 workshops in almost all space science disciplines, as specified above. The workshops have taken place in 21 developing countries and more than 1000 students have participated in them. In 2019 we are organizing another two workshops and adding also two additional host countries to our list.

Concerning the associated fellowships, their number has been very stable since the start of the programme in 2010. A total of 51 visits have taken place, most of them in Europe and USA, with several publications of results as the outcome. Practically all fellowships have served to enhance and expand the knowledge acquired in a new research area.

The validity of the CBP pedagogical concepts is shown in a very steep learning curve of most students during the workshops as well as in a very efficient knowledge transfer. The deep relationship established between international experts and students during the two weeks of each workshop is fundamental for helping the latter in their careers. The importance of the relationship is also proven in the many cases of research visits by former workshop participants to leading institutes throughout the world, in the framework of an CBP associated fellowship but not limited to it.

The students' satisfaction level with respect to the workshops is very high, as measured through questionnaires. The evaluation question related to "significant benefit in attending the workshop" is answered almost unanimously with maximum satisfaction.

VIII. THE FUTURE

While the results are so far very satisfactory, and COSPAR plans to continue with the CBP along the same lines, we have decided to take action on three points further to discussion during the COSPAR Scientific Assembly in 2018:

- Necessity of understanding better the efficiency of the CB workshops. While we have qualitative answers showing the usefulness of the Programme, we do not have quantitative results in terms of relating a workshop to the later career of participants. As an answer to this we have created an Alumni structure with one member of the PCB acting as its Chair. Every workshop held from this year on is expected to create an individual cell of this structure, self-organised by its participants, with one of the students acting as Alumni Delegate. The aim is to organise a yearly event per cell, i.e., a videoconference, by which the former participants of a single workshop can interact and give feedback about their careers, especially as they relate to their workshop participation. We expect a high level of involvement of former students in these events. It should help them maintain a close contact to COSPAR and to colleagues in the field. It could also be a source for recruiting young people as lecturers or data analysis specialists for future workshops. We have many individual examples of former workshop participants helping to organise a later workshop (one member of the renewed Panel on Capacity Building (PCB) was even a student at our first workshop), but the Alumni structure is especially suited for helping

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with this aspect. Understanding the individual careers after a workshop will also allow us to look more closely into diversity questions, going beyond the level we can ensure in an individual workshop itself (as we aim through gender quotes, geographical distribution, etc.

- Homogenisation of the different areas in the CBPis also seen as a necessity. In order to introduce greater interaction between the responsible members of the different disciplines, we have started to hold bimonthly PCB videoconferences. Written procedures for preparation, execution as well as financial control of a workshop are in the process of being drafted as a result of the first meeting. These procedures should help ensure that all areas are treated equally, and also that the principles on which the COSPAR CB Programme is based are well understood, shared and executed by all members of the PCB at each organized workshop. Additionally, homogenisation will secure acceptable ratios of local to COSPAR funding, and of local to regional participants, but also gender diversity where it is needed. An important measure to homogenise the diverse areas is the introduction of biannual calls for workshop proposals. In March and October the PCB decides on workshops to take place between 9 and 20 months later.
- Reflection about the possibility of creating a new type of workshop built around very small satellites (i.e. Cubesats, or Nanosats). Multi-disciplinary work could be fostered at these workshops which would be aimed at younger students than those participating in the typical COSPAR CB workshop (i.e. pre-graduates, even high school students). A high level of team building would be one of the distinct characteristics of such a workshop, stretching through the different disciplines necessary for a practical project around a small satellite. Given the level of COSPAR finances, and to avoid jeopardising the traditional CB Programme, a different funding model would need to be pursued, in which large institutions (UNESCO, EU) but also big private sponsors could contribute. Such workshops could represent COSPAR's educational answer to the new era of small satellites, aiming to help the developing world to avoid missing out on the opportunities provided by these new technologies. The planned COSPAR symposium and CB workshop on small satellites in November 2019 are a perfect platform for giving such ideas concrete form by discussing them with specialists in this area.

IX. SUMMARY

The CBP is seen today as one of the flagship activities of COSPAR. After almost 20 years of activity we can look back with pride on the 35 capacity building workshops with more than 1,000 students in developing countries which have contributed significantly to the space scientific activities in the regions in which they have been held. While we plan to continue with a similar pace of activity in the coming years we are introducing changes which should make the Programme better and wider in scope:

- We have created an Alumni organization to attract younger scientists and encourage them to maintain a durable relationship to COSPAR;
- We have introduced half-yearly calls for workshop proposals to ensure fairness vis-a-vis the different disciplines, as well as streamlining procedures for organizing and conducting the workshops;
- We are evaluating the feasibility for a new workshop type of multidisciplinary nature, devoted to small satellites and aimed at younger students.

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Cosmic radiation environment modelling for the ESEO mission

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***Abstract*— The development of the European Student Earth Orbiter (ESEO) was announced by the European Space Agency Education Office for students interested in the space exploration. The ESEO-TRITEL Team, supported by the Centre for Energy Research, Hungarian Academy of Sciences, joined this international cooperation by the development of the ESEO satellite version of the TRITEL 3D silicon detector telescope. Previous version of the TRITEL detector has been already operated successfully on board the European Columbus module of the International Space Station (ISS) and another version was installed in the Russian segment of the ISS as well. In the ESEO-TRITEL experiment the anisotropies in the radiation field, the effects of the Earth shadow and the South Atlantic Anomaly (SAA) will be analyzed. The results will be compared with the fluxes calculated with the new AP-9 and AE-9 trapped proton and electron models, and possibly also compared against the previous AP-8 and AE-8 models for exploring differences. In this work the space radiation environment was reconstructed for the ESEO mission with the different models and the new results were compared to the ones obtained from the older model.**

Keywords*— *ESEO; TRITEL; trapped particle radiation; dosimetry

I. Introduction

The European Student Earth Orbiter (ESEO) project was announced by the European Space Agency (ESA) in 2008 for students to acquire hands-on experience on real space project. Three Hungarian students' groups joined the mission to develop a subsystem and two payloads to the satellite, including the ESEO- TRITEL team. The development of the TRITEL three-dimensional silicon detector telescope began in the Hungarian Academy of Sciences Centre for Energy Research several years ago. Absorbed dose, LET spectra in three directions, average quality factor of cosmic radiation and dose equivalent can be determined from the measured spectra [1]. After years of hard work ESEO was launched on 3 December 2018, but unfortunately most of the payloads, like the TRITEL detector, have not been switched on ever since. The planned mission time was 6 months with the possibility of extending it to one more year. Important orbital parameters of ESEO can be found in Table 1.

Since the original environmental modelling has been outdated by now, a new study was made to determine the trapped particle environment for a hypothetical mission using the older AP8/AE8 and the new AP9/AE9 models.

TABLE I. ESEO Orbital parameters

Orbit type	Sun synchronous, circular
Altitude	575 km
Inclination	97.5°
LTDN	10:30

II. Trapped energetic particle models

For more than two decades the AP8/AE8 trapped particle models [2,3] were the standards for spacecraft design, and still they are the widely accepted models. These, however cannot benefit from the tremendous data that has been collected over the years, they only depend on two static maps measured decades ago. They also lack probability distribution and correct statistics and it has been proven that they over and underpredict measurements [4]. That is why the need for a new model arose. AP9/AE9 trapped particle models [5] use almost every available data collected since the 70s, of course omitting the data needed for the benchmark. They provide both measurement and gap-filling errors and also account for dynamic variations of space weather processes. They were also made to easily incorporate future datasets for improvement, such as datasets from the Van Allen Probes [5]. With the former models, two types of calculation could be made at solar maximum or at solar minimum. A major difference is that there is no solar-cycle dependence in AP9/AE9. It was left out because solar activity is highly unpredictable and for longer missions where solar cycle driven space weather effects become important, dynamical variations are statistically included in the model.

AP9/AE9 can be run in three modes: (1) mean mode, which only computes mean flux without uncertainties; (2) perturbed mean mode, which uses a random perturbation, consistent to gap-filling and measurement errors; and (3) the Monte Carlo mode, which uses autoregressive time-evolution model to get perturbed uncertainties and also an estimate of the dynamic variations due to space weather processes. These modes can be run resulting in mean average values or in user defined percentile levels.

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III. TRAPPED PARTICLES ENVIRONMENT FOR ESEO

In the following section the AP8/AE8 at solar minimum and maximum; AP9/AE9 mean, Monte Carlo mean and Monte Carlo 5th and 95th percentile models are compared to each other. Since AP8/AE8 models calculate mean fluxes, it can be compared only to the mean fluxes, but the 5th and 95th percentile fluxes are also shown to indicate uncertainties. All fluxes were calculated with ESA's SPace ENVironment Information System called SPENVIS [6]. For AP8/AE8 the threshold flux for exposure was 0.1 $cm^{-2}s^{-1}$. To model the worst possible cases with AP8/AE8 for protons solar minimum, for electrons solar maximum condition was considered [7].

Figure 1 compares the orbit averaged (a) integral and (b) differential proton fluxes using the different trapped particle models for ESEO for a hypothetical mission starting from the 1st September 2019 for 0.5 years. This mission time and length was chosen to model a future switching on of the TRITEL telescope. It shows that AP8min overestimates fluxes under 1 MeV and over 50 MeV but underestimates in between these regions compared to AP9. TRITEL would measure between 18 MeV and 10 GeV [8], mostly where the fluxes were underestimated. Higher fluxes mean slightly higher count rates in the region where only around 720 counts per seconds are expected at maximum with the current 1.2 mm aluminum shielding [9]. Compared to this, the maximum count rate of TRITEL is 50000 cps. It means that slightly higher count rates could be expected in the main region, which improves statistics. Also, slightly thinner shielding could have been chosen to get similar results. However, 1.2 mm was also chosen to be equivalent to the lower limit of the effective thickness of a typical spacesuit. The figure also shows that AP9 mean and AP9 Monte Carlo mean is similar to each other, but the Monte Carlo mode models predict higher fluxes above around

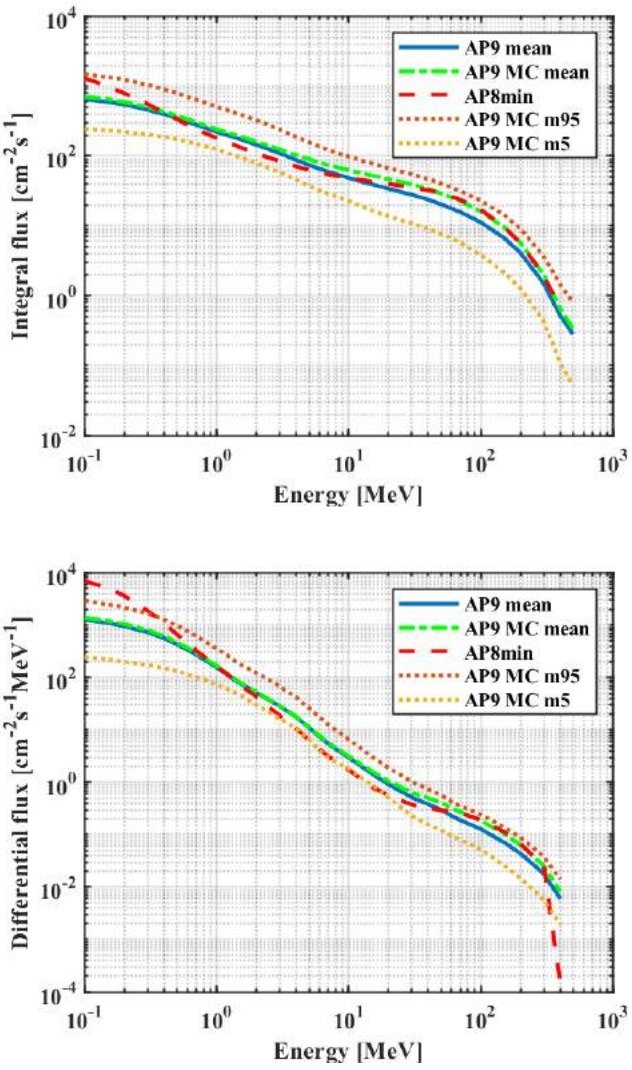

Fig. 1. Orbit averaged (a) integral and (b) differential proton fluxes for ESEO using the AP9 and the AP8 models for a hypothetical mission starting from the 1st September 2019 for 0.5 years.

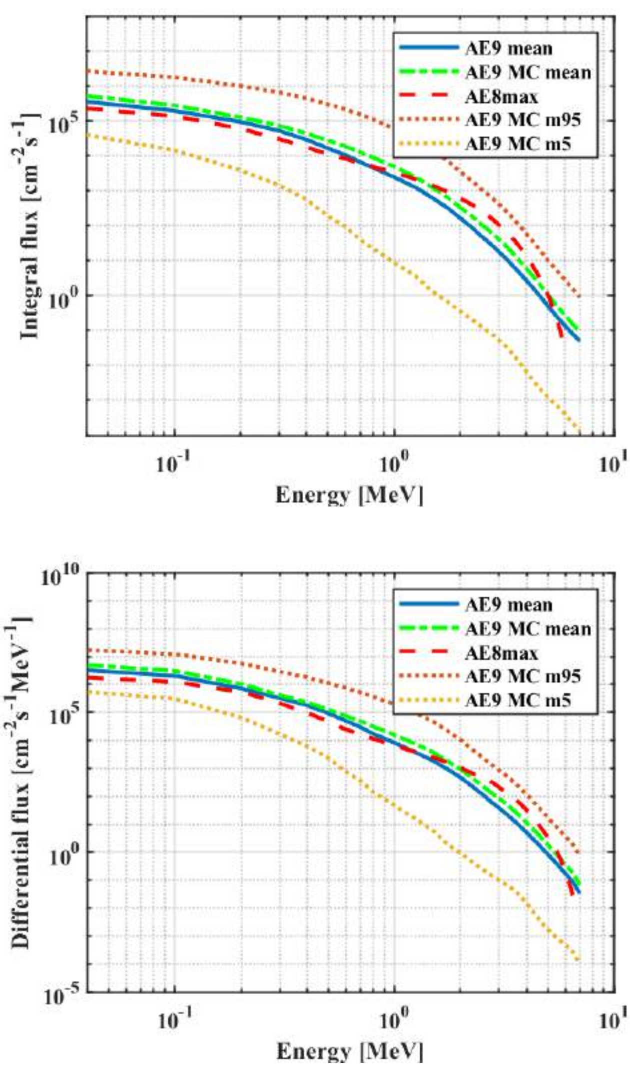

Fig. 2. Orbit averaged (a) integral and (b) differential electron fluxes for ESEO using the AE9 and the AE8 models for a hypothetical mission starting from the 1st September 2019 for 0.5 years.

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10 MeV, making the results there more similar to AP8. However, AP8 cuts off earlier than the new models.

Figure 2 compares the same data but for electrons. AE8 orbit averaged flux is similar to the new model at low energies, but overpredicts above 1 MeV, right in the measuring range of TRITEL and cuts off earlier as well. This could mean smaller real count rates for electrons.

For the next two sets of figures, all data was modelled with AE9/AP9/SPM V1.50.001 package developed and distributed by NASA. Figure 3 shows trapped proton integral flux at 2 MeV along the orbit for one day, 1st September 2019 as a function of geographical longitude and latitude. One square corresponds to 60 seconds. Nonzero flux values contour the South Atlantic Anomaly (SAA). The shape of SAA is similar, but the overall extent of the shape is bigger for AP9. Although AP8min has higher maximum, the peak of SAA is smaller and at a different position. Since in the model the peak is larger and it takes approximately 12 minutes to go over it, it would improve the resolution if reading would be around 6 minutes instead of the currently used 10 minutes. If the satellite passing only at the SAA very edge, it only takes about 4 minutes, which would be measured not accurate enough with 10 minutes of reading time.

Figure 4 shows trapped electron integral flux at 0.1 MeV along the orbit for one day, 1st September 2019 as a function of geographical longitude and latitude. One square corresponds to 60 seconds. Nonzero flux values contour the SAA and polar regions. Similar to proton fluxes, AE9 calculates a larger dimension for SAA, but less electron flux for the polar regions. This also means that shorter reading time would improve data resolution in these regions. The maximum of the flux is almost equal in both cases, the main difference is the shape of regions of interest.

IV. Summary

Within the framework of this study, the differences between the widely used older AP8/AE8 and newly developed AP9/AE9 trapped energetic particles models were investigated. It was found that there are smaller differences in the orbit averaged

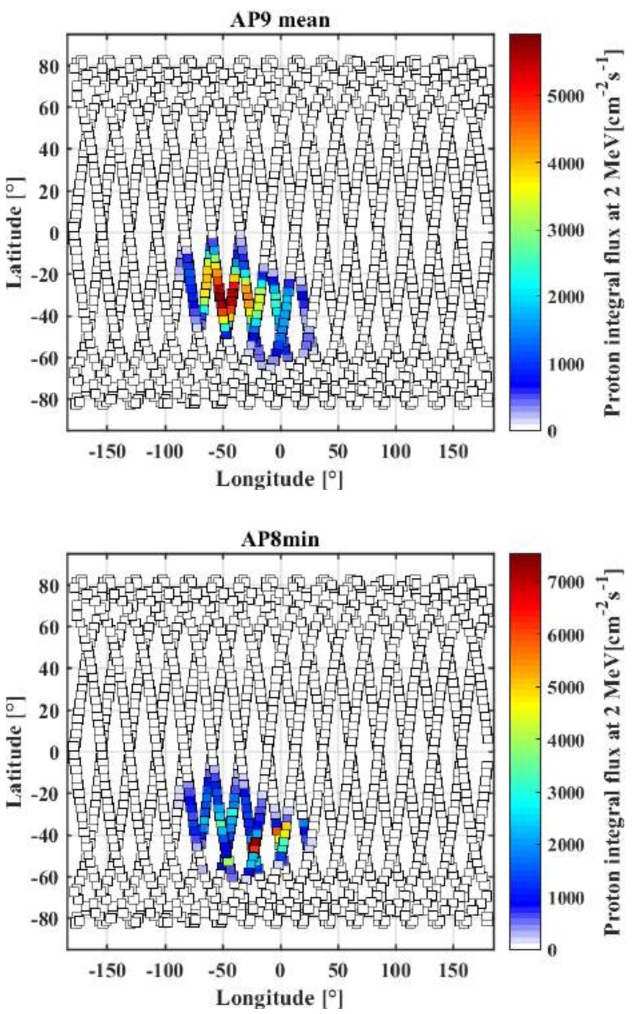

Fig. 3. Proton integral flux at 2 MeV with (a) AP9 mean and (b) AP8min as a function of geographical longitude and latitude. Flux was calculated for only one day, 1st September 2019.

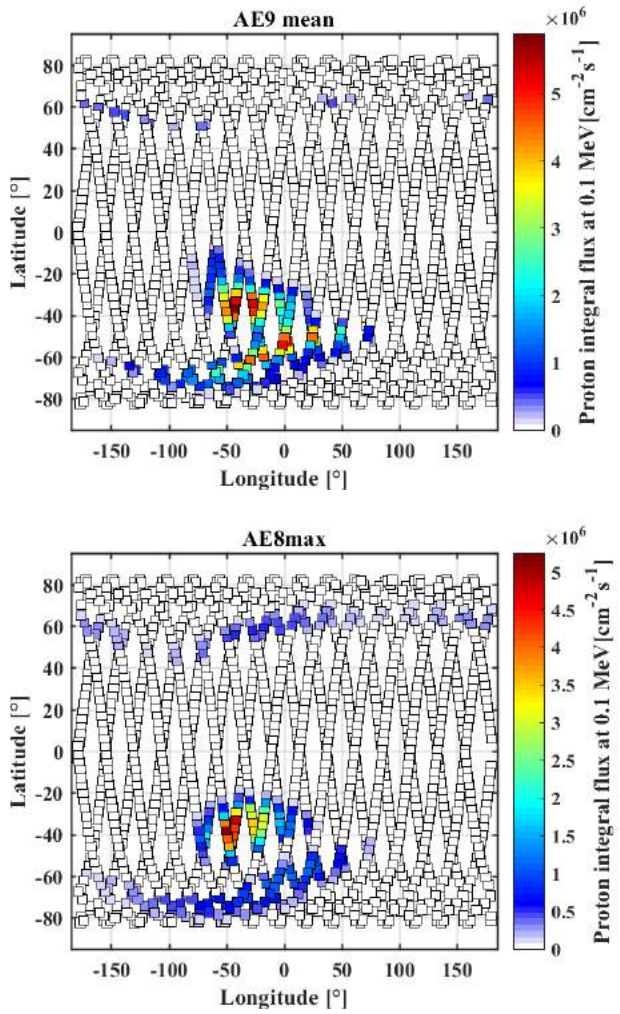

Fig. 4. Electron integral flux at 0.1 MeV with (a) AP9 mean and (b) AP8min as a function of geographical longitude and latitude. Flux was calculated for only one day, 1st September 2019.

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fluxes. AP8/AE8 under and overestimates AP9/AE9 in regions. Also, the extent of the SAA is different; if the integral flux along the orbit was examined at a given energy. Based on these, shorter spectrum acquisition time is recommended in the future, to have a reasonably accurate resolution of the data measured in SAA, to be able to compare models with data. It has been previously shown, that AE9 under and overpredicts quantities around SAA, since it lacks proper electron data near that region [5]. However, the developers are aware of these shortcomings and the model will be improved with future measurements.

The aim of this work was to study the effects of the new model on detector development through the example of ESEO. If our instrument can be turned on in the future on ESEO, the difference could be studied not only in theory but through measurements as well and would be helpful designing similar detectors telescopes in the future.

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Lessons Learnt From Operating ESEO Educational Spacecraft

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***Abstract*— Since 2003, the Microsatellite and Space Microsystems Lab at the University of Bologna (UniBo) has extended his research activities to the design of a ground segment for small satellites missions. In the framework of the European Student Earth Orbiter (ESEO), an ESA Education Office project for the development of a microsatellite mission, with SITAEL S.p.A. as the Industrial System Prime Contractor, the first-generation GS has been upgraded to support ESEO operations. UniBo was in charge for the design and development of the Mission Control Centre (MCC), the implementation of the primary ground station for telemetry and telecommand operations, and of the secondary one for the downlink of payloads data. ESEO was launched on December 3rd, 2018. Soon after launch, the activities planned for the Launch and Early Orbit Phase (LEOP) were forced to be held back due to the lack of success in commanding the spacecraft. After weeks of coordinated efforts among spacecraft operators, spacecraft engineers and ESA technical staff, LEOP activities could be resumed, thanks to the support of the radio amateur community and of ES5PC ground station in Tartu. Since then, new challenges are coming, which need to be faced for ESEO mission to advance further: this paper provides a thorough perspective of the achievements and lessons learnt during these months of operations.**

Keywords: Ground segment, Flight Operations, ESEO

I. Introduction

The European Student Earth Orbiter (ESEO) is a project of the Education Office of the European Space Agency (ESA) aimed at providing students with unparalleled hands-on experience to help preparing qualified space engineers for the Europe's future [1]. This is achieved through the design, development, integration and testing of a micro-satellite to be launched in a sun-synchronous low Earth orbit. The objectives of the mission are: taking pictures of the Earth for educational outreach purposes, providing dosimetry and space plasma measurement, and testing technologies for future education satellite missions. SITAEL is the prime contractor and responsible for the ESEO platform and mission implementation whilst the university network provides the scientific and technological payloads and develops the ground segment. UniBo team is in charge of the design and development of the mission control center as well as the implementation of the primary ground station (for TeleMetry and TeleCommand - *TMTC* - operations), and of the secondary one (for the downlink of payloads data).

ESEO was launched on December 3rd, 2018: soon after launch, the roadmap originally conceived for the operating the spacecraft had to be re-planned to overcome some unexpected issues.

This paper offers an overview of the efforts towards the operational phase of ESEO mission, describing the issues encountered, investigations performed, solutions and/or workaround identified. The manuscript is organized as follows: the next section includes details about the ground segment implemented for ESEO operations. Afterwards, the activities performed in order to get ready for launch are presented focusing on the preparation and testing of the flight procedures. The following two sections cover LEOP and commissioning, with emphasis on the tools which revealed useful during critical phases, such as distributing the ground segment and setting up a tool for telemetry visualization/collection from multiple sources. Finally, conclusions are drawn, together with the lessons learnt so far.

II. ESEO Ground Segment

The primary TMTC ground station operates in the Ultra-High Frequency (UHF) band for uplink and downlink. It consists of two Yagi antennas: one, in the amateur band (430-440 MHz), dedicated to the ESEO satellite and another, operating in the commercial UHF band (400 MHz), for future applications. With respect to the first ground station implementation, the current one is designed under the Software-Defined Radio (SDR) paradigm, which allows fast and economical reconfiguration of the ground station since the signal is digitally processed at software level [3].

The Secondary Science Data ground station operates in S-band, and uses a parabolic dish antenna with a septum dish feed.

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A dedicated control room is furnished with technical equipment to support the mission monitoring and control related activities. It hosts three workstations and the Radio Frequency equipment such as switches, High Power Amplifiers and radio interfaces. The first workstation is dedicated to the control of the RF front-end and the Antenna tracking. The second workstation is a spare for future missions and the third workstation is entirely dedicated to the ESEO mission. It hosts the mission control system, which is all the software dedicated to the accomplishment of the ESEO mission, from the database storage to the Spacecraft Monitoring and Control (M&C) system for commanding the spacecraft and visualizing telemetry.

Fig. 1. Mission Control Center at UniBo premises.

The design of the M&C system allowed UniBo students to develop a key background in the field of ground operations. A great effort has been devoted to design an intuitive and easy-to-use graphical user interface, helping the spacecraft operator to handle TMTC data within the short duration of the satellite visibility pass. Specifically, the M&C system has a threefold purpose: a) the selection of the desired commands to send b) the visualization of the received satellite telemetry data and c) the connection to a mission database for storing the downlinked data and retrieving the various commands and satellite parameters, if necessary.

III. Launch Preparation

The preparation and test of the flight procedures were the core activity of the University of Bologna during the preparation-to-launch phase. To this end, a list of draft operations in the form of raw commands sequences were provided by SITAEL. These sequences have then been expanded and tailored to the Ground Segment setup, with particular focus on the M&C Software interface outlining the so-called flight operations procedures (FOP).

A flight procedure is a sequence of operations that the spacecraft operator executes in order to command the spacecraft toward a given state. The desired spacecraft state is thus the objective of the execution the operational procedure. For ESEO, 192 flight procedures were developed to characterize all ESEO's state transitions, both basic and complex, and laying down plans on how to handle anomalies. Each flight procedure is reported on a spreadsheet with the following fields:

- Title;
- Duration: Time needed for execution;
- Criticality: Degree of criticality defines the needed authorization and the personnel to be involved in the planification for the procedure execution;
- Objective: Description of the final state of the spacecraft after the completion of the procedure;
- Introduction: Brief general description and applicability of the procedure;
- Procedure description: step by step operations to be accomplished to achieve the objective (i.e. sequence of set up and commands to be sent from the M&C System);
- Caution: warnings on the application of the procedure;
- Applicable and reference documents: link to related manuals;
- Related procedures: link to procedures that may be needed during or soon after the current procedures;
- Needed Authorisation (if any).

All flight procedures were tested on the Avionic Test Bench (ATB) to check their effectiveness in leading the spacecraft into the target state. The setup of the test emulates the real spacecraft operational conditions as much as possible. Limitations in matching the real scenario were present though, such as missing attitude sensors and GPS readings, and the absence of doppler shift in the radiofrequency link. A workstation runs the MCS software which interfaces with another workstation operating Software defined radio hardware. All sent commands and received answers were logged into an archiving system as in a real mission scenario.

Along with the flight operational procedures, operational workflows (i.e. lists of actions for the spacecraft operator to perform, arranged in an "event tree" configuration) were agreed with SITAEL on the base of the final ESEO's design. A total of 10 workflows were deemed sufficient for ensuring a safe commissioning and mission operation:

- LEOP START: establish the first contact with the satellite. Three different final states foreseen: No signal, Nominal, Emergency signal;
- LEOP LOST: a set of procedures and crosschecks is suggested before returning to LEOP START;
- LEOP NOMINAL: guides the operator through a series of basic health checks before moving on to the platform commissioning;
- LEOP-S3: provides the operations to bring the spacecraft from an emergency state (in LEOP) to the nominal LEOP state (i.e. LEOP NOMINAL);
- COMMISSIONING START: applied for each platform subsystem, guides the operator to perform specific platform checks and has three possible outcomes: platform Commissioning failed with or without criticality or ok;

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- COMMISSIONING NONCRITICAL: guides the resolution of non-critical failures in platform commissioning toward the payload commissioning;
- COMMISSIONING CRITFAIL: guides the resolution of critical failures in commissioning toward a noncritical condition to continue platform commissioning and then payload commissioning;
- COMMISSIONING PAYLOADS: guides the payloads commissioning. Failure of any payload commissioning is handled internally towards a recovery or final report;
- NOMINAL: guides the nominal operations;
- DISPOSAL: guides the satellite shutdown.

These workflows were then made available to the ground station operators in form of a wall poster. The rationale for employing workflows in addition to the FOPs lies in that the former provide a picture of the mission at higher level, highlighting how each FOP interconnects with the others and possibly having roles in different mission phases. FOPs and workflows together also allow for a comprehensive operations testing and training phase during launch preparation.

IV. Lauch and Early Orbit Phase

On December 3rd, 2018 at 19:34 CET, the European Earth Student Orbiter was successfully launched into space onboard of a SpaceX Falcon 9 launcher from the Vandenberg Air Force Base in California (USA), as part of the Spaceflight's SSO-A SmallSat Express mission.

The LEOP is the first and the most critical part of any mission. The spacecraft, after a series of vibrations, accelerations and mechanical stresses due to the launch, is exposed to the actual space environment for the first time; the operations team starts interfacing with it in this phase. ESEO mission was no different, it showed several unexpected behaviors which forced the team to readjust the entire operations concept, procedures and processes. Being ready to unpredicted behaviors and reacting fast to them is perhaps the most pivotal lesson learnt from the mission. The following subsections summarize the problems encountered during LEOP and the solutions put in place to overcome them.

A. Decoding ESEO's Telemetry

The first TM data from ESEO was received on December 3rd 20:25:21 UTC: a type 5 beacon which included the expected values of the Fault Detection Isolation and Recovery (FDIR) parameter and the TMTC telemetries. At the same time the first unexpected event occurred: as the beacons kept arriving to the ground, it become quite clear that primary TMTC ground station was achieving a poor performance in decoding the ESEO packets.

Investigation on the problem revealed the cause of the low downlink capabilities to reside both on a high level of environmental noise at UHF band, and on some improvements needed in the decoding part of the LabView-based SDR SW. After a new SW version developed and released, the downlink performances became more in line with other ground stations. The new SDR SW was developed using GNU Radio environment, an open-source software development toolkit for signal processing [4], which is widespread among the radio amateur community.

B. ESEO first contact

Shortly after the launch, ESEO's downlink seemed to work properly but it appeared that the commands coming from the GS were not received by the spacecraft. Several Materials Review Boards (MRB) were held along with ESA's experts and SITAEL's engineers to investigate and solve the issue. Time is a crucial constraint in this phase and actions were taken on different fronts: from the inspection of the RF chain and the M&C SW, to the check of the antenna pointing. In parallel, other ground stations were contacted, some of them having significant higher EIRP than the primary TMTC one, for establishing a first contact with ESEO. A success in establishing an uplink to ESEO using a higher EIRP could hint toward a desensitization of the onboard receiver. The chronological schedule of the attempts is the following:

- 03/12/2018: Forlì's GS (ESEO Primary TMTC GS);
- 19/12/2018: Vigo's GS (ESEO Secondary TMTC GS);
- 22/01/2019: Munich's GS (Primary Payload data GS);
- 28/01/2019: ES5PC's GS (Amateur station in Estonia).

The first successful contact with ESEO was established during the attempt from ES5PC, an amateur station located in Estonia (Fig. 2). The station, with its 4.5m parabolic dish and vacuum tube power amplifier, is capable of delivering 1kW RF power, which proved to be enough to uplink TCs to ESEO.

Fig. 2. ES5PC's Amateur Station (ES5PC Photo)

Having a solid network of ground stations is fundamental in a space mission, and coordination among partners is a key factor during LEOP; certainly, this is another lesson learnt from ESEO. The main cause of the desensitization of the ESEO receiver is still unclear.

C. ESEO Operations

A reliable link to extend the main TMTC GS has been therefore developed. The extension allowed to replace *de facto* the antennas and workstation driving the RF front-end at the primary TMTC GS with ES5PC's RF equipment. More

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specifically, a TCP/IP connection was set up for the M&C workstation being able to send and receive packets to and from Estonia. This was possible thanks to the modular implementation of the Mission Control Center, featuring separated workstations for the M&C task and for the RF front-end handling task: this resulted to be a convenient layout for setting up a distributed ground segment.

Once the new setup was validated, the LEOP operations could be resumed following the LEOP NOMINAL workflow. During these operations, all the sent commands and any relevant observation during pass were logged on Tracking Pass Reports. Reports were then analyzed with SITAEL in order to agree on the operations for subsequent passages. In parallel, the spacecraft operators worked on the upgrade of Forlì GS HW to raise its transmitted EIRP.

During LEOP, the on-board computer experienced a Single Upset Event which made the temporal separation between beacons change from 60 seconds to 572 making an On-Board Data Handling (OBDH) system reset needed. In addition, the TMTC subsystem experienced an issue with the High-Power Amplifier (HPA): the switching-on of the HPA got slightly delayed with respect to the start of the beacon transmission, resulting into a loss of modulation of the received packets on ground.

Investigations on the anomalous behaviour of the HPA delay were extensively carried out on the ATB searching for the root cause of this behavior. However, there was no success in trying to replicate the same anomaly. Nevertheless, the issue could be overcome by forcing periodically a reset of the TMTC through a dedicated High Priority Command (HPC). The need for periodic TMTC reset slowed down the operations toward towards LEOP completion and led to the addition of a new flight procedure.

The main operations performed from then on were:

- Update Time via Time-Tagged telecommands;
- Update TLE via a set of 10 telecommands;
- OBDH reset via HPC;
- Request of House Keeping (HK) History, HK Pages and TM data;
- Set of several on-board parameters via telecommands (e.g. Magnetorquer Actuator Gains);
- TMTC Main Reset via HPC.

D. Ground Station Network and Data Visualization

With ESEO transmitting beacons in the amateur UHF band, the radio amateur community was deeply engaged in collecting as much information as possible on the satellite state. A public database was developed to store telemetry from contributors all around the world. Three alternative ways are provided for contributors to write on this database, namely

- SiDS protocol [6]: collects the packets from the radio amateurs implementing SiDS forwarders;
- SatNOGS: collects the packets from any source which uploads its passes to the website [8][5] (mainly from the radio amateur network);
- Alma Mater Ground Station (AMGS) Forlì: packets decoded from the primary TMTC GS.

Simple and fast data visualization is essential not only given the educational purpose of this project, but also from an operational point of view. Ground segment and operations engineers shall monitor the status of health of the platform continuously and plan actions from the MCC accordingly.

The tool selected to make these data available is GRAFANA, an open source project for visualizing metrics [7]. Supporting integration for several database (MySQL in our case) GRAFANA allows the user to visualize all ESEO telemetries at the following link: http://eseo.ddns.net/. Each parameter (e.g. SOLAR PANEL Temperatures) is represented in a dedicated panel and grouped into several dashboards (e.g. Beacon Power), see Fig. 3.

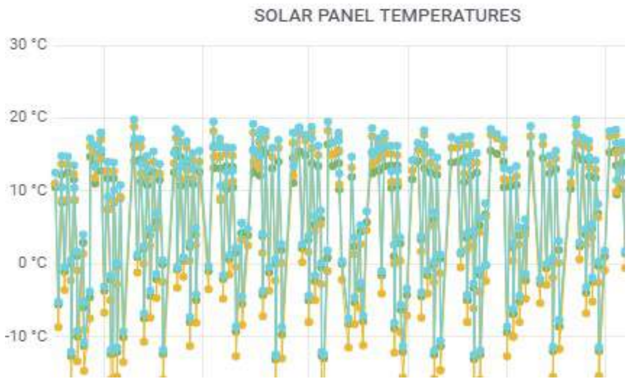

Fig. 3. ESEO Solar Panel Temperatures (source: http://eseo.ddns.net/)

V. COMMISSIONING

The Commissioning phase is aimed at running the set of operations and checks needed to declare the satellite ready to begin its nominal mission. For ESEO, one of these operations is the transition from the post-launch spinning attitude to a three-axis stabilized attitude. On 21 March 2019, all the commands needed by the spacecraft to determine its orbital position and attitude were uploaded on-board.

During this phase, an off-nominal attitude of ESEO was detected from its telemetry. Following the same approach as for other non-conformity, an investigation started in coordination with MRB meetings. This gave rise to a list of actions to be performed in the following passes, namely: i) the nominal beacon rotation was forced to AOCS beacon only, to collect all possible information on attitude; ii) magnetometers and magnetorquers data were analysed in detail through dedicated telecommands and iii) to check the output of the onboard International Geomagnetic Reference Field (IGRF) model, which was as expected. Despite the nominal attitude was not achieved, other actions to advance ESEO mission educational outreach were undertaken, which are described in the following.

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A. *AMSAT UK Activation*

In this non-nominal yet safe condition, the activation of the AMSAT-UK Communication System was greenlighted, to mark the start of the educational payloads commissioning. Developed by University of Surrey (UK), this payload provides a continuous stream of satellite and science data for educational purposes and it is the first amateur payload to use L-band communication. Therefore, switching on this payload had also the benefit of providing independent source of telemetry data.

On April 12^{th}, 2019, AMSAT-UK started operating nominally. From 10:43 UTC to 14:18 UTC, 270 valid packets were received from the U.K., Japan, Australia and Brazil. All payload telemetry channels were functional and operative within valid ranges; all telemetry generated from the payload itself was consistent with pre-delivery testing [9].

AMSAT-UK was unexpectedly shut down by an OBDH reset occurred during an unknown ESEO state of continuous transmission (see sub-section B).

B. *Latest developments: rejection train*

Roughly one orbit later, at about 12:17 UTC, ESEO started transmitting rejection (REJ) messages continuously, one packet per second. Since no telecommands were transmitted to ESEO during this orbit, due to a lack of visibility from the uplink ground station (ES5PC's station), the possibility that the behavior was triggered from ground was soon ruled out. Investigations on the TMTC SW and tests on the ATB performed by SITAEL led to the hypothesis of self-oscillation at TMTC level: S/C is transmitting to itself REJ responses triggered by its own transmitted packets. It is unclear however what may have triggered this auto-excitation, and whether this may be linked to the interaction between AMSAT and the platform RF system (although pre-launch EMC tests showed no signs of such a risk).

During this period, ESEO experienced an automatic transition from mode 3 (Damping and Safe) to mode 4 (AOCS Normal Sun/Eclipse-Nominal) and from mode 4 to safe mode 2 (S2) due to a malfunction of the MWM (set "not reliable" and switched off).

Several unsuccessful attempts were performed to unlock ESEO from this uncontrollable state, both from the ES5PC ground station and from another amateur station, I1NDP, in Italy. None of them was successful: at the moment of writing, ESEO is still transmitting one REJ every one second, which prevents any further advancement towards mission completion since the RF system is not full duplex and cannot be commanded while transmitting. Nevertheless, ESEO keeps transmitting also beacons, which allows for continuous monitoring of its status of health. The data in these beacons shows that nine months after launch the power system (solar arrays, batteries, power management and power delivery boards), the OBDH and the RF transmit chain are operating nominally showing no signs of degradation.

VI. CONCLUSIONS

After almost 9 months in orbit, the in-flight experience gathered with ESEO spacecraft unveiled many challenges.

A first lesson learnt from operating the spacecraft is the strong need for flexibility and responsiveness to unexpected problems. Nevertheless, each unpredicted issue shall be considered as a chance of professional growth.

Working closely with ESA's experts and SITAEL's engineers has been an invaluable source of technical knowledge for the university team. Planning ESEO passes through daily updates with system engineers and reviewing the state of the spacecraft through weekly meetings with ESA were essential in order to understand how to recognize and prevent anomalies, how to identify a problem and how to deal with it.

Management of time and resources proved to be pivotal for the success of ground operations, since many tasks must be performed in the very short time frame set by the satellite visibility over the ground station, allowing also for contingencies. A solid ground station *network* supporting the mission is mandatory. Coordination among partners is fundamental in a critical phase as the LEOP is; this is a lesson certainly learnt from operating ESEO.

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