ENHANCING SPACEFLIGHT SAFETY WITH UOS3 CUBESAT

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ABSTRACT

Earth orbits are becoming increasingly congested. This will not only impact future space operations but also become a concern for the population on the ground; with more spacecraft being flown, more objects will re-enter the atmosphere in an uncontrolled fashion. Parts of these satellites can reach Earth surface and endanger the ground population (e.g. ROSAT or UARS satellites). A student-run project from the University of Southampton aims to build a 1U cubesat (approx. 10 by 10 by 10 cm satellite), which will gather data that will improve the accuracy of re-entry predictions. The cubesat will record and deliver its position and attitude during the orbital decay, thus providing validation data for re-entry prediction tools. This will reduce the risk to the ground population because more accurate prognoses will allow mitigation measures to be implemented in the areas at risk. The mission could also allow the risk of collision between spacecraft to be estimated more accurately thanks to improvement of the atmospheric models. This would give the decision makers more complete information to use, for instance, in collision avoidance manoeuvre planning.

1 INTRODUCTION

The first spacecraft, Sputnik 1, was launched on 4 Oct 1957 [1]. More spacecraft have been launched since, many of which have been left on-orbit [2]. The fact that more spacecraft are being launched than are being removed from orbit has led to an increase in the number of objects orbiting the Earth. This is because spacecraft at high altitudes are relatively unaffected by atmospheric drag, which is the major force that makes spacecraft naturally leave orbit and re-enter the atmosphere [3]. Until mid-October 2015, the catalogue of space objects that can be tracked and whose positions were made publicly available through www.space-track.org [4] has grown to 15 268. This increase in the number of tracked objects was also caused by collisions and fragmentations, which produce small objects that are unlikely to survive re-entry. However, entire spacecraft are still being left on-orbit and will eventually re-enter in an uncontrolled manner.

It is impossible to accurately predict how many new spacecraft will be launched, at what rate, into what orbital regimes, and how many of them will be deliberately manoeuvred out of orbit [2]. This affects predictions of the total number of objects on-orbit by orders of magnitude [5]. However, if any spacecraft are launched into low-Earth orbit, some of them will eventually decay under the influence of atmospheric drag and re-enter Earth's atmosphere. Depending on the design and composition of the re-entering spacecraft, up to 40% of its original mass could survive the re-entry and reach Earth's surface [6].

The frequent re-entries of spacecraft (approx. one large object per week [6]) raise concerns about potential ground casualties that such events could cause. This has led to several institutions and countries implementing standards, e.g. NASA [7], and legislation, e.g. France [8], that address this risk.

Being able to predict re-entry in advance enables mitigation measures to be implemented to reduce the risk to the ground population. However, at present, re-entry can be predicted with an accuracy of 2 to 28% of the remaining lifetime in orbit [6]. A "rule of thumb" relative re-entry prediction uncertainty of ±20% is recommended by Pardini and Anselmo [6].

For a spacecraft located in a circular orbit of radius r around a planet with gravity parameter μ (398600 km^3/sec^2 for Earth), the orbital period is given by Eq. (1) [3].

$$\tau = 2\pi\sqrt{\frac{r^3}{\mu}}. \tag{1}$$

For a spacecraft in a circular, 200 km altitude orbit, the orbital period is approx. 1.5 hours. Even with 2% re-entry prediction error bound, 24 hours before the re-entry the prediction is accurate to 33% of the orbital period, i.e. 29 minutes. For longer lead times, the time window, in which the spacecraft might re-enter, is larger. In the above example, 74 hours before the re-entry, the spacecraft could re-enter anywhere along its orbit. This means that the satellite could reach Earth's surface over any latitude it flies over, which is given by the inclination of the orbit [9]. For many orbits used by earth observation satellites, namely Sun-synchronous orbits, that implies all latitudes with the exceptions of the poles [3]. That being said, the re-entry will take place along the satellite's ground track. Therefore, the satellite cannot impact any location on the globe. The possible re-entry locations from the above 200 km circular orbit example, 74 hours before the re-entry, are shown in Fig. 1.

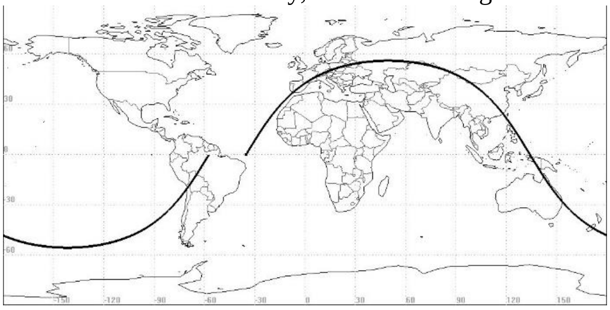

Figure 1: Possible re-entry locations of a satellite in a circular, 200 km altitude orbit with inclination of 55°. Predicted 74 hours before the re-entry with 2% uncertainty.

Such low accuracy of re-entry prediction makes implementing efficient risk mitigation measures difficult because of the large area over which the spacecraft might re-enter [6]. This large area means that for every specific location at risk, e.g. a city, the probability that the satellite will impact this specific point is extremely low. This low probability, combined with relatively small area that can be affected due to limited size of the debris, makes it irrational to issue a decision to implement mitigation measures. In other words, current re-entry predictions do not provide information that is actionable. However unlikely, a re-entry could cause casualties nonetheless. Therefore, improving the accuracy of re-entry prediction, and thus enabling actionable re-entry warnings to be issued, is of importance to both the decision makers and the ground population that is potentially at risk.

The inaccuracies associated with re-entry prediction have several different origins, which are well reviewed by Pardini and Anselmo [9] and references therein. These uncertainties are largely associated with modelling of the acceleration due to atmospheric drag, a_D, an object of mass m, cross-sectional area A, and drag coefficient C_D, moving through a fluid of density ρ at speed v, will experience. This acceleration is given in Eq. 2 [3].

$$a_D = \frac{1}{2}\rho v^2 \frac{A}{m} C_D. \tag{2}$$

The specific sources of re-entry prediction uncertainty include:

1. sparse or imprecise satellite tracking data, which mean that re-entry prediction might have to be done based on inaccurate satellite ephemerides
2. unknown satellite shape and altitude, which affects the area A in Eq. 2
3. inaccuracies in modelling the spatial and temporal variability of atmospheric density ρ
4. possible variations in solar activity that cannot be forecast far in advance, which could unexpectedly change the atmospheric density ρ
5. modelling interactions between the spacecraft and the atmosphere particles, which are captured by the drag coefficient C_D

Four out of five mentioned sources of re-entry prediction uncertainty (points 2, 3, 4, and 5) are associated with modelling of the atmospheric drag; either directly (2, 3, and 5) or indirectly (4). These sources of uncertainty may interact and thus result in different overall re-entry prediction error for a specific re-entry case, even if the same models and practices, which gave highly-accurate predictions for other cases, are used [9].

Accuracy of the satellite drag modelling also affects the confidence with which possible on-orbit collisions can be forecast. This is because drag modelling affects the accuracy of the ephemerides [10], which in turn impacts how accurately the probability that two objects will collide can be estimated [11]. Thus, improving drag modelling accuracy would directly increase the safety of space assets by helping to prevent their destruction during collisions. Preventing orbital collisions, through better collision forecasts and avoidance manoeuvres, reduces the number of pieces of debris added into the environment. Collision avoidance is not the most effective space debris mitigation measure; however, it is one of the means to limit the growth of the number of space debris. If the quantity of debris does not increase significantly, the collision risk of all the satellites will not increase much further, thus enabling the continued use of the resource of space [12].

Thus, improving the accuracy of satellite drag modelling could improve the safety of the ground population, as well as the safety of the space assets themselves.

Fundamentally, theories, for example predicting the atmospheric drag or solar activity, can only be improved by corroborating them further [13]. This is to say by comparing theories to experimental data in a process that is often referred to as validation [14].

Due to the fact that every re-entry is different, e.g. as far as solar activity or the initial orbit are concerned, [9] and physical properties of the re-entering objects are not always known, such validation data for re-entry prediction are scarce. Thus, the safety of spaceflight could be improved by recording the re-entry profile of an object and comparing them to predictions. This object should have well-defined geometry and drag coefficients, as well as known attitude. Its position and attitude should be recorded throughout the decay with as high accuracy as possible.

Table 1: Mission objectives of UOS³ and corresponding success criteria.

ID	Objective statement	Success criteria		
		Minimum	**Nominal**	**Full**
1	Design, build, test and operate a CubeSat using primarily resources from the University of Southampton.	Successful flight qualification test according to launch provider specification requirements.	Deployment of CubeSat in Space with subsequent radio contact.	Delivery of at least one photograph as well as position and attitude time history for nominal mission duration.
2	Obtain visible-band photographs of Europe and transmit them to the ground for public relations and outreach purposes.	Successful operation of camera and photo downlink capability demonstrated in laboratory conditions.	Take a photograph in space and downlink it at least partially.	Take a photograph in space with Earth at least partially visible and downlink it completely.
3	Generate data to validate space object re-entry prediction tools.	Successfully demonstrate correct experiment operations in laboratory conditions.	Record and downlink at least one data point after deployment.	Record and downlink experiment data for nominal mission duration.

Such a need could be met by a spacecraft capable of recording its orbital position, ideally with accuracy better and spatial resolution higher than the publicly available ephemerides, i.e. two line element sets (TLEs) [15]. Such a mission should also be capable of recording its attitude at a sufficient frequency to allow reconstruction of the attitude profile between consecutive attitude measurements. The spacecraft fulfilling this mission should be small enough to enable its drag coefficients to be easy to characterise in hypersonic wind tunnels that are available in Europe, i.e. should have diameter smaller than approx. 0.2-0.6 m [16]. Finally, if the spacecraft is relatively inexpensive, several instances of it could be flown in multiple missions and thus generate the validation data in a range of space weather conditions, increasing the robustness of the validation.

The University of Southampton has decided to address this scientific need by flying a 1U cubesat, approx. 10 by 10 by 10 cm satellite [17], the University of Southampton Small Satellite, or UOS³ [18]. Ideally, a satellite used to generate re-entry validation data should be spherical, which would simplify modelling of its interaction with the atmosphere. However, few actual satellites are spheres and so the UOS³ will present a more representative test case. The more challenging shape of the satellite is offset by the fact that it will carry on-board position sensors. If such sensors were to be accommodated in a spherical satellite, the craft would need to be larger, and thus more expensive to launch.

This mission will be described in more detail in section 2. The UOS³ project has been conceived and is being carried out mostly by the students of the University. The involvement of the different student groups, the backgrounds of which extend beyond aerospace engineering or, in fact, science and technology, is described in section 3. Even though the UOS³ is still being constructed, several lessons have been learnt by the team over the duration of the project. These will be summarised in section 4.

2 THE UNIVERSITY OF SOUTHAMPTON SMALL SATELLITE, UOS³

The University of Southampton Small Satellite was conceived to address the above mentioned need to improve re-entry prediction tools. Since its inception, the UOS³ has sparked world-wide interest and five institutions, including the European Space Agency, have expressed formal interest in accessing the data that the cubesat will gather.

Furthermore, this satellite will be the first one built at the University of Southampton; this is deemed a considerable achievement and hence one of its primary mission objectives is to return a photograph of the Earth taken from orbit, which will be used for publicity purposes.

The mission objectives of UOS³, together with different levels of success criteria for each, are given in Tab. 1. They represent the intent of flying the satellite in-orbit but, even should this not take place, UOS³ will be deemed a success nonetheless, thanks to the gain in expertise of the participants.

The origins of this mission and organisation of the programme will now be briefly described. Then, the suite of sensors, capable of delivering the data that will address the set mission objective number 3, will be presented, together with an outline of the satellite platform that will be used to fly the proposed sensors.

2.1 HISTORY AND ORGANISATION

The UOS³ programme was started in the second quarter of 2014. The discussion about building UOS³ was prompted by attendance at the ESEO Lecture Course organised by the European Space Agency [19]. This workshop brought together students from across Europe, some of whom had built cubesats in the past. It was a unique opportunity to learn about organising such projects in a university environment. Two further workshops, one organised by the UK Space Agency and one by the UK organisation for Amateur Radio Satellites

(AMSAT-UK), played a major role in the UOS^3 programme as well.

These workshops exposed the project leads to more people who had been involved or interested in building cubesats, some of whom were also members of the University but were unknown to the project leads due to the size of the institution. These workshops enabled collaboration and knowledge transfer, and eventually contributed to the start of the UOS^3 project.

The biggest constraints for UOS^3 were the overall cost and duration of the project. Unless the project generated sufficient interest and gathered enough supporters, it would likely not be continued once its initiators have left the University. Moreover, no budget was allocated for the project at its outset and, without sufficient support, financial backing would not be gained.

Complexity of the satellite had to be kept low due to the fact that no complete cubesat has ever been built at the University of Southampton. Consequently, designs of only parts of such satellites were available to build upon. Moreover, the fact that UOS^3 will be the first University of Southampton cubesat meant that few processes were in place to enable intra-University collaboration on a project of this scale. It was clear that students from many different faculties would need to be involved, for example aerospace and electronics engineering. Due to the structure and legislation of the University, running a single, assessed project with students from multiple faculties is currently impossible. Thus the work has to be split into several smaller projects, each specific to one faculty. Reducing the complexity and number of on-board interfaces simplifies the organisation of student groups to design and produce the satellite, as less configuration control has to be put in place. This not only makes interface control easier, but also reduces the schedule overhead associated with it.

2.2 PAYLOAD

The orbital decay trajectory has to be recorded using on-board sensors to give a higher temporal resolution (frequency of measurements) than could be achieved by, for example, tracking the spacecraft using ground sensors. In order to provide satisfactory spatial accuracy, star sensors or global navigation satellite system (GNSS) receivers had to be used.

Initial launch-provider enquiries revealed that it was unreasonable to hope that sufficient funding for the launch of a satellite larger than a 1U cubesat would ever become available. Due to volume and associated power constraints that are inherent to such spacecraft, star sensors were not considered for navigation any further.

The only commercially-available GNSS receiver that appeared feasible to be flown on a 1U cubesat platform due to its relatively low power consumption, was the OEM615 by NovAtel [20]. The GNSS receiver distributor recommended using it in conjunction with an active antenna by Antcom [21].

The peak power consumption of the GNSS receiver is up to 1 W when using only the GPS satellite constellation. This necessitates covering as much of the external surface area of the satellite with solar cells as possible, thus restricting the use of Earth horizon sensors or photodiodes. Therefore, it was decided to use a relatively low-power magnetometer (AK9863 by Asahi Kasei Microdevices [22]) to estimate the attitude of the craft. It is augmented with sun-vector sensing performed by measuring the solar array currents [23]. Such a combination of sensors limits the complexity of the spacecraft and reduces the net power consumption of the payload, while satisfying the 5° attitude knowledge requirement [23].

The attitude of the spacecraft will be stabilised using a passive magnetic system, which consists of a permanent magnet that aligns one of the cubesat axes with the local magnetic field, as well as hysteresis rods that dampen the oscillations [24]. Such an attitude control subsystem (ACS) choice reduces the number of interfaces on board UOS^3. However, it also necessitates calibration of the magnetometer to be able to extract useful attitude knowledge in the presence of a strong, self-induced magnetic field. Similar spacecraft have flown before [25]; therefore, it is expected that UOS^3 mission objectives can be met with the proposed design.

The final piece of payload of UOS^3 is a camera, which will deliver images that will be used for publicity and outreach purposes. Following a similar trade-off to that performed for ICUBE-1 [26], the same camera was selected for UOS^3. Namely, the µCAM-II by 4D Systems [27] will be flown. Unfortunately, the signal from ICUBE-1 has never been received [28]; therefore, the selected camera does not have any flight heritage. However, it is hoped that any camera faults would have been discovered during ICUBE-1's testing or will be identified during the UOS^3 test campaign.

2.3 SYSTEM DESIGN

Due to the mentioned budget and schedule constraints, the UOS^3 design philosophy favours the use of flight-proven hardware. This allows less testing to be performed on the component level without increasing the mission failure risk beyond what is deemed acceptable. This reasoning has influenced the selection of the payload sensor suite, camera, as well as attitude control subsystem architecture, which were described in section 2.2.

The same rationale was applied to the selection of the UOS^3 bus design. Moreover, wherever possible, manufacturing the assemblies and subsystems at the University of Southampton is favoured. This enables exposing as many students to the project as possible, thus increasing the educational return of the mission. It also reduces the cost of the cubesat.

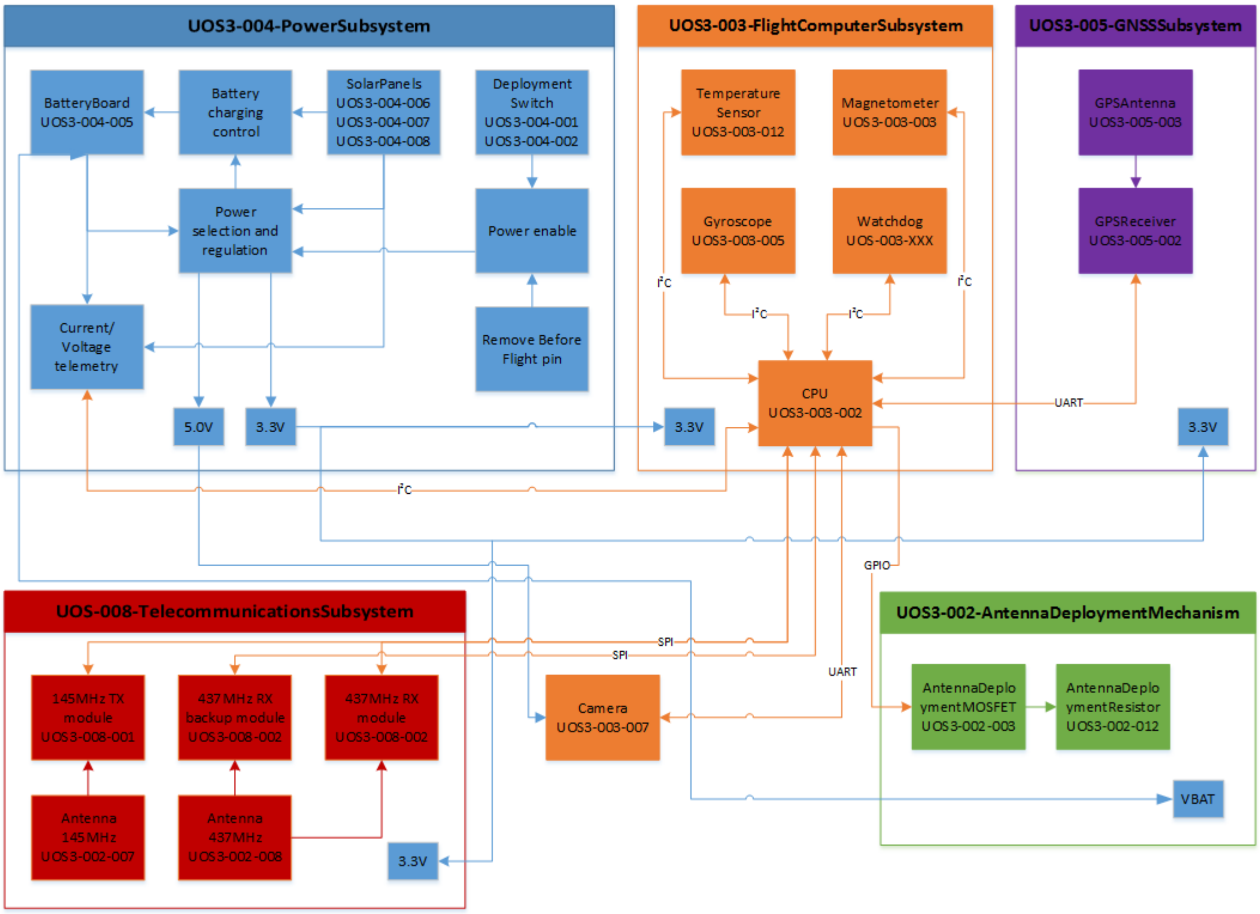

Figure 2: Block diagram of the UOS³ cubesat system. Passive components, such as structure or attitude control subsystem, have been intentionally omitted for clarity.

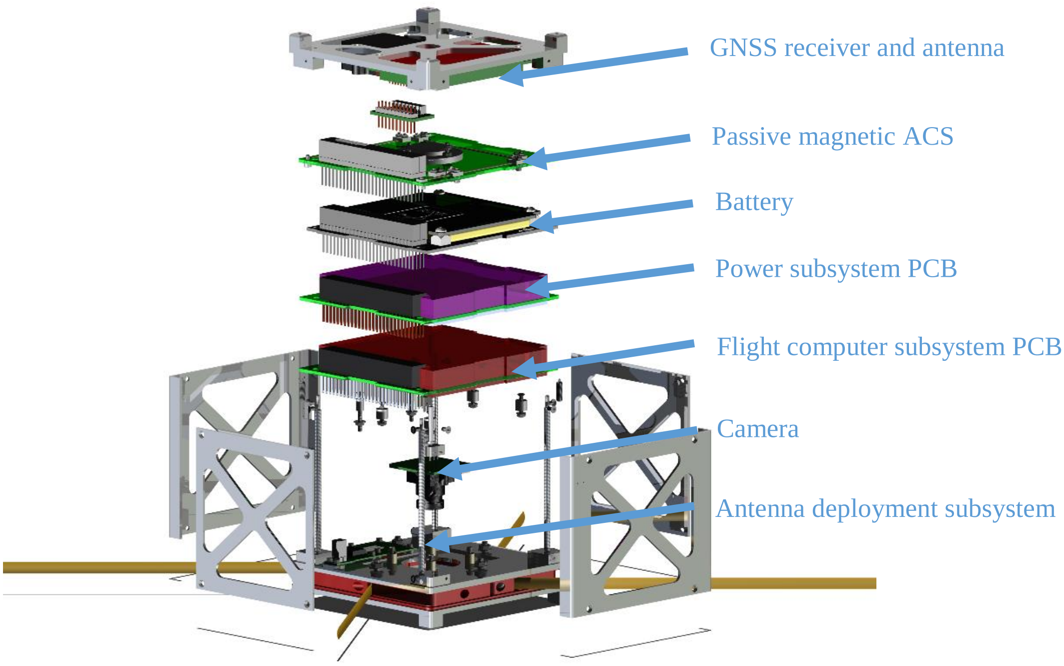

Figure 3: Exploded view of UOS³. Solar panels, located on the surfaces of the structural panels, have been omitted for clarity.

Furthermore, utilising the University's expertise and facilities was set as the first UOS^3 mission objective. The University of Southampton can boast a broad base of expertise in space activities. This base extends across many faculties and includes both upstream capabilities, e.g. development of space technology or spacecraft design, and downstream capabilities, e.g. exploitation of technology, communications, earth observation and navigation. What has been missing in the past is a catalyst to bring all these activities together and the UOS^3 cubesat programme is that catalyst, which is reflected by this mission objective.

The block diagram of the UOS^3 satellite system is shown in Fig. 2. Passive components, such as the load-bearing structure and passive magnetic ACS, have been omitted from the figure for clarity.

The on-board computer subsystem, which also includes all the sensors except for the GNSS receiver and antenna, is based around a 32-bit ARM® processor, namely the TM4C123GH6PM [29] by Texas Instruments. Most on-board communications are realised over an I^{2}C bus, with an exception of several SPI and UART connections. This reduces the number of connections that have to be routed on the printed circuit boards (PCBs), limited in size by the cubesat form factor. Use of I^{2}C also simplifies connecting PCBs to each other, and removes the need to have a dedicated general purpose input-output (GPIO) pin of the main microcontroller assigned to only one sensor. A dedicated GPIO pin would be required if the communications were realised over an SPI bus, for example. In order to limit the complexity of the entire spacecraft, only one main microcontroller will be used and that has a limited number of GPIO pins.

The power subsystem gathers energy using custom-built solar panels supplied by DHV Technology [30]. Each of the panels houses two triple-junction, GaAs solar cells, manufactured by AZUR SPACE Solar Power [31]. The custom shape of the solar panels enables them to interface with an in-house manufactured load-bearing structure. The energy gathered by the panels is stored for use in eclipses in a 10 Wh battery manufactured by a UK-based company, Clyde Space [32]. The solar cells' output is maximised by implementing a maximum power point tracking algorithm.

The UOS^3 structure houses all the subsystems in a configuration that provides optimum mission performance. The accuracy of the attitude sensing is improved by maximising the physical separation between the magnetometer and the ACS magnet, thus reducing the strength of the self-induced magnetic field. The chosen spacecraft configuration also enables the GNSS antenna to be pointed along the zenith, thus providing the best positioning accuracy.

Telecommand uplink is achieved at a frequency of 437 MHz. A hot-redundant receiver is incorporated into the telecommunications design to cope with failures of the primary receiver. Spacecraft telemetry, experimental data (position and attitude measurements), as well as images will be downlinked over 145 MHz. Use of these frequencies was decided upon because they are commonly used by radio amateurs around the World and thus many ground stations should readily be available for UOS^3 to use. Also, a simplified and faster frequency coordination process can be followed for these amateur frequencies, thus reducing the overall programme duration and cost.

Accommodating the antennae, one pair of which spans 978 and the other 316 mm, in the 10 by 10 cm cubesat envelope is a challenge. This is normally overcome by deploying the antennae after the cubesat is released from the launch vehicle. It was decided to use tape spring antennae, similar to what was successfully used by F-1 and M^3 cubesats [33, 34]. These will be stowed inside the allowed cubesat envelope by wrapping them around a 3D printed plastic structure and restraining them from accidental deployment using a nylon wire. Once the UOS^3 is deployed in space, this wire will be split by the heat generated by running current through a resistor. The accumulated strain energy of the antennae will cause them to deploy once the restraint of the wire is removed. This mechanism is based on the design that was successfully used on-board the Xatcobeo cubesat [35].

All the above mentioned subsystems have been accommodated in the 1U cubesat envelope according to the arrangement shown in Fig. 3. The solar panels are bolted onto the structural panels, which have been exploded in Fig. 3. Solar panels were excluded from the figure for clarity.

3 STUDENT INVOLVEMENT

Over the timespan of the academic year 2014/15, UOS^3 involved 15 students in the final year of their undergraduate programmes, who worked on it as their final projects. In the year 2015/16 it involves 12 new final-year undergraduate students and two Master students. As the development of the mission progresses, more students benefit from being able to take part in this large collaborative project.

This section describes the student groups that are involved in the project, how they benefit from it, and how the collaboration between various groups is achieved. The lessons learnt in the process are considered valuable to other universities that wish to develop cubesats because most University projects focus on students working individually or in small groups with similar background. Thus, enabling several projects to work in a larger programme that spans many different disciplines and involves multiple individuals or small groups of students may prove challenging in the university environment.

3.1 ENGINEERING

Most cubesat projects tend to involve students from various areas of engineering. This is understandable, given that spacecraft are complex autonomous systems.

Consequently, their design and manufacture requires many hours of skilled labour.

The UOS^3 is no different in this respect, as it primarily involves mechanical, aerospace, and electronic engineering students. They have been taking part in all design, manufacture and verification phases of UOS^3, except for definition of the top-level requirements and architecture. The latter tasks were performed by volunteer postgraduate students and staff of the University.

The structure of an integrated Master of Engineering (MEng) course at a UK university, such as Southampton, can involve a group design project (GDP). In a GDP, a number of students from the same discipline would typically design, manufacture and test a piece of hardware [36]. At the University of Southampton, the GDP takes place in the final year of the MEng course. UOS^3 involves students from several GDPs at any given time. Flow of information is facilitated by postgraduate students that oversee the programme, and serve as project managers and system engineers. Their involvement also ensures continuity of knowledge throughout the course of the programme. This is because postgraduate studies last several years, whereas MEng students are only involved for up to one academic year.

Unlike most GDPs, the students working on UOS^3 have to collaborate with other groups working on different pieces of hardware and software that will form part of the same system. This exposes the students to an industry-like situation, because few large-scale engineering projects are carried out by a single group of people. It necessitates stricter configuration control, because decisions taken by one group of students affect others. Moreover, the software and hardware interfaces between the products delivered by each group have to be looked after more carefully. Lastly, schedules of the different groups have to be synchronised to ensure that every group will have access to the assembled cubesat hardware to conduct the integration and verification of their product. Finished designs of certain groups are inputs to the work conducted by others, which also has to be coordinated. Even though the responsibility for this systems engineering and programme management rests on postgraduate students, students from all the GDPs are naturally exposed to it. Therefore, they have an insight into how such tasks are carried out, which is a unique educational experience.

3.2 PHYSICS AND ASTRONOMY

Apart from engineering students, UOS^3 also involves final-year Physics and Astronomy students that calibrate the magnetometer, which will be flown aboard the craft. The two students who chose this project are enrolled on the Physics with Space Science degree programme, which combines a core physics degree with specialist options on space-based applications (e.g. remote sensing, study of the interaction between the solar wind and Earth, and space-based astronomy) and courses on spacecraft engineering. These students have to understand how UOS^3 is designed and what the self-induced magnetic field will be in order to make sure that the calibration is meaningful. Furthermore, the students gain an insight into how the satellite will be operated. Lastly, because the calibration is being carried out in parallel with the satellite design and manufacture, the students gain an insight into actual engineering and project management. These are unique opportunities, which are not normally given to most Physics students, but which capitalise on the courses taken as part of the Physics with Space Science degree. These opportunities will, therefore, definitely be useful to the students when they pursue their careers and begin to work on larger-scale space missions or in other fields of science and engineering.

This group of students also prepares the method of processing the data that the UOS^3 mission will gather, such that higher-level data products may be distributed to the scientific community. In the case of UOS^3, this will be attitude history rather than just histories of the solar array currents and raw magnetometer readings, for example. Understanding such data processing chains is crucial for students who aim to work in the field of space science, because in their future careers they will work in one of the steps of this chain. Being able to understand the whole process, having already experienced it in its entirety, allows the students to better understand where they fit in the big picture. Working on UOS^3 might be the only opportunity for them to gain such insights.

3.3 FINE ART

Being able to experience the satellite creation process has been a stimulus for fine art and graphic arts students at the Winchester School of Art (WSA). The remainder of this section gives examples of how satellites can be interpreted and serve as an inspiration for an artistic process. Having an insight into this perspective may prove valuable to other institutions wishing to expand how they use space for tertiary education.

Students at WSA were first introduced to the cubesat project through Deep Highly Eccentric, a group exhibition of artwork that explored ideas of abstraction and distance in relation to artificial satellites. Lectures were scheduled alongside the exhibition, covering aspects of satellite history, their relation to surveillance, our geopolitical sphere and their influence on culture. Art students were invited to develop art works in response to the UOS^3 cubesat, which has become an extracurricular project where student participation is voluntary.

The UOS^3 project proposes a valuable professional experience within an art and science context. It enables art students to engage with different disciplines and their methodologies and invites them to consider alternative forms of communication and dissemination of the project themes. One of such invaluable and unique insights is witnessing aspects of the engineering process as well as learning about space debris.

To encourage a breadth of thinking around the subject matter and foster creativity, the project was further introduced by combining astronautics, cultural and associative perspectives. To a non-specialist, satellites may appear to be relatively mysterious objects: photographic images of satellites are scarce and selectively shot. Most representations are “artist impressions” and illustrate satellites floating in space like science-fiction spacecraft from another world or future. A lack of information around them adds to a sense of their technological abstraction, which is amplified through their physical distance. This absence of information potentially opens up space for different interpretations – such as a mythologizing of satellites: imagining them as contemporary gods of communication that influence our lives from afar. Not unlike the Greek god Hermes or the Roman adaptation, Mercury, who are said to represent themes of trade, travel, trickery and thieves and guide souls to the underworld. Like these gods, satellites cross geographical and metaphorical boundaries as they bridge the journey between worlds.

If anthropomorphized, the Pleiades satellite image of the Envisat satellite also takes on a different reading – a form of caring interaction, one satellite literally looking out for another. Or when the Philae lander accidentally captured one of its legs in the shot when taking photographs of the Comet 67P/Churyumov-Gerasimenko, it unwittingly followed contemporary trends and produced a “satellite selfie”.

Satellites also offer a different way of seeing; by producing images that are multispectral and panchromatic, bringing new material and expanding dialogue around lens based history and landscape photography.

Additionally, the influence of satellite technology on artists and authors can be seen in works such as “Olympic Rainbow”, made in 1988 by Nam Jun Paik and involved satellites around the world transmitting images and sounds which the artist edited in real time and re-transmitted back across the planet. Similarly, artist Trevor Paglen drew upon satellite positioning data to locate and photograph secret spy satellites, using long exposures to reveal what is not supposed to exist.

Although it is not yet known how students will respond to UOS^3 in detail, it is an exciting proposition that invokes thinking about the future and space within an art context and is a rich resource for creative potential.

3.4 OTHER STUDENT GROUPS

Students from virtually any discipline can volunteer to work on the UOS^3 in their spare time. Their work is overseen by one of the University’s many societies (the University of Southampton Spaceflight Society [37]). This society, a student-run organisation, is tasked with building the ground station that will be used for UOS^3 operations. The Society has undertaken similar projects with high-altitude balloons, and is thus one of the groups within the University that is best prepared for this task. On the other hand, the nature of the society enables any student to participate in the UOS^3 programme by working on hardware that directly interfaces with the satellite. It thus gives a broad range of students an opportunity to gain direct insight into the cubesat hardware as well as programme structure; an experience that would not otherwise be possible during any university project.

UOS^3 has also sparked interest in the student-run newspaper at the University of Southampton, the Wessex Scene [38]. The involved students decided to track the progress of the satellite development and publish regular updates. This exposes these students to technical journalism, and further disseminates information about UOS^3. This exposes more students to how the project is run, and the satellite designed and manufactured.

Lastly, UOS^3 is a case study indicating the beginning of a new space era. It was used in this context in several lectures given to history students, allowing them to appreciate the fact that, unlike a few decades ago, not only select few countries can now build and operate satellites.

4 CONCLUSIONS

The UOS^3 programme would likely never have happened had it not been for workshops that exposed its initiators to individuals who had worked on similar projects. This has made the current project leads realise that starting a project to build and launch an educational satellite might not be easy, but certainly is achievable. This proves that workshops like this are definitely beneficial and bring the intended results.

Space is often used in tertiary education of students with science and technology backgrounds. However, it can be useful in enhancing the education of other students, for example history or fine art. Involvement of the Winchester School of Art in the UOS^3 programme shows this and serves as an example to other educational institutions that space can be used to educate many more students than traditionally done. One area where the UOS^3 programme could still improve is involving law students to interpret the international laws governing spaceflight, e.g. the liability convention, or marketing students to work on branding of the project.

The most important lesson that has been learnt over the course of the programme is how crucial it is to involve postgraduate students and staff to ensure continuity of knowledge over the several years that the programme is likely to take. What also proved beneficial in this respect was employing some of the students, who were or will be involved in the programme, as interns.

Overall, the UOS^3 cubesat programme is an example of how a relatively simple mission can bring large benefits to both the host educational institution, by enabling its students to work on a large, collaborative project, as well as the scientific community. The interest of major research institutions around the world in the data delivered by the UOS^3 mission proves that this project -addresses an important scientific need.

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