2nd Symposium on Space Educational Activities, April 11-13, 2018, Budapest, Hungary

Development of a Wildlife Tracking Satellite for International Space Station Deployment

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***Abstract*—WUSAT-3 aims to demonstrate a novel direction-finding space system which can be used to track the location of a low power signal originating from the Earth's surface. This system could be used to track global migration of animals using lightweight, low power tags as a complementary system to existing GPS technology. As part of a 6-year project, WUSAT-3 aims to design, optimise and test a 3-unit CubeSat which can be launched from the International Space Station into Low Earth Orbit for a 28-day mission providing a proof of concept for the tracking system. WUSAT-3 is in its 3rd year and each of the CubeSat subsystems are undergoing concept refinement and technological development. A Concurrent Systems Engineering approach has been implemented to aid rapid simultaneous development of subsystems. This paper will present the development of the subsystem designs through the use of concurrent engineering to meet the mission objectives.**

Keywords—CubeSat, Migration, Direction-Finding, University

I. Introduction

A. Application of CubeSat

The current location and data collection system used for studying and protecting the environment, ARGOS, has been operational since 1978 and utilises the Doppler effect to locate a source anywhere on Earth [1]. By mid-summer 2018, ICARUS (International Cooperation for Animal Research Using Space) aims to provide additional capability by providing a space system which tracks wildlife globally using a GPS tagging system; whereby a signal is picked up by the satellite, the data is processed and sent to the International Space Station (ISS) before being transmitted via a downlink to a ground station [2]. WUSAT-3 aims to demonstrate a novel direction-finding space system which can be used to track the global migration of very small animals using lightweight, low power tags that would not be required to record and transmit GPS data. Fig. 1 illustrates the CubeSat space system. A successful mission would demonstrate the technology, providing the potential for development of a future network of low cost satellites with increased ground coverage and reduced tag weight when compared to the other initiatives. This is of importance to scientists studying the migration of small birds as GPS tags can be too heavy for the migration of the organism.

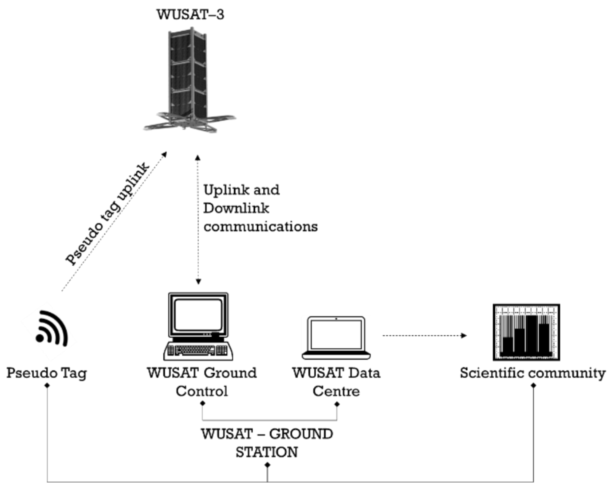

Fig. 1. WUSAT-3 CubeSat space system

As part of the University of Warwick's Masters of Engineering program, a multidisciplinary team of students have further developed the previous two years of work and are building on the designs of the subsystems. This includes enhanced development of project management, stakeholder engagement and technical designs of the University CubeSat project.

B. WUSAT-3 Aims and Objectives

WUSAT-3 aims to launch a CubeSat that can demonstrate the technology to track global migration of small animals using lightweight, low power tags.

To achieve the aims of the project the following objectives were set for 2017/2018 academic year:

- To communicate with stakeholders to verify and confirm mission requirements.
- To expand upon the previous year's subsystem designs, and ensure that updated mission requirements are met.
- To commence development of the thermal control, data handling and communications subsystems.
- To implement a Concurrent Engineering approach for simultaneous development of subsystems.

- To fulfil the academic learning objectives by working harmoniously as a multidisciplinary team.

C. *WUSAT-3 2017-18 Project Team*

The primary objective of this project is to serve as a final year group project for Warwick engineering master's students, worth 25% of their final year mark. The multidisciplinary team is formed of 7 students studying a range of specific streams, in this instance: two studying each of electronic, mechanical, and systems engineering, as well as one mechanical and manufacturing engineering student. The aim of this group project is to enable the team to experience what it is like to solve a substantial engineering problem in a manner similar to that of an industry project, gaining invaluable team working, communication, and project management skills.

To support the achievement of these aims, a number of deliverables are required throughout the year. Initially a project brief and poster (WUSAT submission to European Space Agency's (ESA) Educational Symposium) are due in the first term, detailing the project's internal objectives and giving an overview of the progress respectively. In the latter stages there are three portfolio submissions: one regarding the design work undertaken in solving the given problem, the second providing evidence of the project management techniques employed, and finally an analysis of the state of the project at completion. The last submissions are a detailed technical academic paper on one aspect of the project and a presentation in which the overall progress is exhibited for evaluation.

II. Project and Technical Management Methodology

A. *Project Set Up*

The WUSAT-3 project is run by project directors Dr Bill Crofts and Professor Julia Hunter-Anderson who remain constant through the succession of different MEng teams. The project directors are responsible for the students developing the necessary skills to fulfill the Master's degree accreditation requirements. Furthermore, they support the communication with sponsors and any external links to the ESA, ensuring the project is eligible for the "Fly Your Satellite!" program. In addition to the core members, there are three PhD students, who have previously been in the WUSAT team, supporting the technical development of the CubeSat. This year, a Bachelor's level student is carrying out research for her dissertation thesis to support certain design decisions. Fig. 2 shows the WUSAT-3 team's set up.

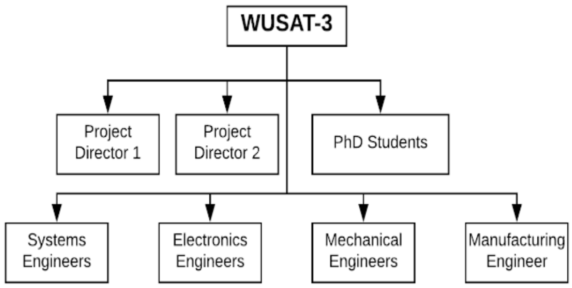

Fig. 2. WUSAT-3 team set up

Each member of the student team is assigned, by negotiation, to a subsystem which aligns to their academic field. Multiple members can be assigned to a subsystem depending on its development stage. In addition to advancing the subsystems' designs, the team also has a responsibility to manage the project and its sponsors, processes and equipment. Each member also chooses an additional administrative or organisational role, i.e. health and safety or marketing manager, to support the management of the project. The team has been allocated a lab by the School of Engineering department where meetings and working sessions are carried out. A progress meeting with the directors is held weekly, with the students creating agendas, recording minutes and chairing the meeting. University resources are used wherever possible, with professors, library resources and engineering facilities used to advance designs.

B. *Systems Engineering*

Systems engineering has been employed throughout the life of the WUSAT-3 project to manage the CubeSat design at a system level.

The generation of the WUSAT-3 requirements are an important detail of how the systems engineering approach has been implemented. The requirements are the drivers of the CubeSat design, which are generated to ensure the end-user requirements are fulfilled. WUSAT-3 requirements have been maintained and updated as the project progresses until a preliminary design is finalised. Further to the creation of requirements, another significant part of systems engineering is the verification of said requirements. Although, currently the CubeSat is not developed enough to verify the requirements, they have been written in such a manner that future teams will be able to create and conduct a verification plan.

Budget tables and margins are exploited to observe the systems compliance to constraining requirements. The mass budget defines the system's mass as a combination of the subsystems, whilst the power budget looks at the power consumption of each of the different subsystems in different operational modes. Margins are used to account for a certain amount of error at both subsystem and system levels.

C. *Concurrent Engineering*

Following some of the team members' involvement in the ESA's Concurrent Engineering challenge and CubeSat Concurrent Engineering workshop, the team recognised the importance of the approach to managing the project and is actively implementing ESA's best practices.

One of this year's objectives was to adopt a Concurrent Engineering approach to allow systematic development while ensuring end-user expectations are of paramount importance. Implementation embodies team values and cooperation to establish effective and efficient communication supported by harmonious multidisciplinary team decision-making.

Within the current team, the division into subsystems was performed to allow all of the subsystems to reach the same stage of design. Regular team meetings are used as working sessions to facilitate efficient communication and achieve design compatibility.

As design and development are iterative processes, Google Drive is currently being used as an active document management system, with a specific WUSAT network drive used as a vault for when documents are completed. Well managed documentation is of crucial importance to allow the transparency of designs and decisions for both current and future team members.

III. Subsystem Design and Development

A CubeSat is typically made up of the following subsystems: Structure and Configuration, Power, Communications, Thermal, Attitude Determination and Control System, Data Handling, and Payload. Mission Analysis is then used to support the requirements analysis, subsystems and operations design. This year, development was focussed in certain areas of the subsystems, as described below.

A. Mission Analysis

One of the biggest areas of uncertainties was mission analysis. As there is currently no definitive information about the deployment date or the ESA requirements to be suitable for the application to 'Fly Your Satellite!' program, a lot of decisions had to be based on extrapolation of the available information. When creating mission requirements, which are essential to shape the design of each subsystem, the general strategy was to follow the industry-imposed standards, created by ECSS, ESA and even NASA, as well as to relate to the requirements of the similar past ESA programs, i.e. 'Build Your Satellite!', implying the deployment of the CubeSat from the International Space Station via the NanoRacks launcher.

Furthermore, assumptions about the orbit around the Earth had to be made. The Systems Tool Kit (STK) software was used to run the simulations of the orbit to both visualise and extract data for calculations to derive a more refined design of the subsystems. For example, the illumination times of the CubeSat are essential to obtain the cold and hot case scenarios of the thermal subsystem, as well as for the calculation of power produced by the solar panels throughout the operational life of the satellite. Moreover, the use of STK helps to analyse the effect of the chosen orbit on mission requirements and selection of the imaging payload.

B. Structure and Configuration

The major advancement to be achieved this year regarding the structural subsystem is the development of a deployment system to allow the antenna arms to release from their stowed position, which is required for launch. This system is being designed such that there is minimal risk of activation while being stored aboard the NanoRacks system to be utilised in the CubeSat's deployment from the International Space Station, with the probability of the antenna arms releasing and damaging NanoRacks being minimal. To guarantee this, SOLIDWORKS finite element analysis is being employed to simulate the vibration to be experienced in the launch to the ISS and understand the modal shapes and fundamental frequencies of the antenna arm geometries. These results are then used to inform decisions in the progression of antenna arm design, as well as how the arms are to be secured before deployment. Further simulations are to be performed in Abaqus FEA to corroborate results and further inform future design decisions.

C. Thermal

Detailed thermal analysis is required to ensure the CubeSat can cope with the harsh environment encountered in Low Earth Orbit (LEO). The design must account for extreme thermal cycling, from -120 °C to +120 °C, with maximum temperatures caused by solar, infrared and albedo radiation plus any internal heat dissipation [3]. Furthermore, the CubeSat's design must be able to withstand the low temperatures experienced when in eclipse, and control the thermal energy transfer from internal electronic components. Initially, a preliminary analysis was completed whereby the worst case hot and cold temperatures the CubeSat might experience were calculated. These temperatures were initially verified through the use of a MatLab steady state model, as well as SolidWorks simulations, where the temperatures were within 10% of each other. The analysis included modelling the outer structure with simplified solar panels, chassis and antennas. An internal analysis was completed on the inner cage, payload, PCBs and ADCS. Currently, a detailed thermal analysis is being completed using ESATAN-TMS, the industry approved thermal modelling software. This will be used to verify our initial designs including an outer coating, and three internal patch heaters distributed within the CubeSat. Table 1 shows the operating temperatures of the internal components, a +/- 10°C margin will be applied to ensure WUSAT-3 meets the ECSS standards.

TABLE I. Component Operating Temperatures

Component	**Temperature Ranges (°C)**		
	Minimum Operating Temperature	***Maximum Operating Temperature***	***Operating Range per ECSS***
Battery	-10	+45	0<t<35
Payload	-40	+55	-30<t<45
PCBs	-40	+55	-30<t<45
ADCS	-35	+75	-25<t<65
Chassis	-40	+80	-30<t<70

D. Attitude Determination and Control System (ADCS)

Previous years have developed a MatLab control system which reduces angular velocity after launch (detumble) and controls pointing direction (slew). The system has been tested on a simple model of the CubeSat in one dimension (with the axis of rotation aligned with the earth's magnetic field). Work this year has focused on designing a system to enable experimental reaction wheel characteristics to be evaluated against the ideal operating conditions. Using low-cost additive manufacturing (3D printing), a test system has been designed to evaluate the torque produced by a range of reaction wheels. The system has been designed in such a way that future teams can adapt the geometry of a single component (by modification of a SolidWorks file) and print a custom part to enable any motor and reaction wheel to be evaluated within 4 hours. In doing this it is believed that future teams will be able to rapidly evaluate and compare ADCS designs (specifically Motor and Reaction Wheel combinations) at negligible costs. It is hoped that by providing detailed design documentation the same approach could be applied to testing many other aspects of the design using low cost methods.

E. Radio Communications

Previously, the payload frequency had been selected and an initial link budget was completed. This year, the system and analysis has been further developed and the optimal components have been selected. The focus is on the design of the ground-to-satellite communication system. A variety of system designs at various frequencies were evaluated and the best design for cost, power consumption, weight and size was selected. This system utilises the existing payload communications system to enable telecommand and the payload downlink to ground, without additional structural changes.

F. Electrical Power

The main developments in this subsystem are the power distribution and switching systems. As the battery used is 3.7 volts, DC-DC converters were picked to convert this voltage to 3.3 and 5 volts for various components. These converters were chosen based on their temperature ratings and efficiencies. For the switching circuit, solid state relays were selected. The specific models have not been decided as the components that the relays would control such as the motors have not been defined yet.

The power budget from 2016-17 also has been defined further by adding component values and calculating powers when possible. The operating phases of the mission listed in the power budget have also been revised. The power available to the satellite has been recalculated to create a more accurate power budget.

IV. Future Work

A. Project Management

The concurrent engineering approach should be adopted by future teams to ensure consistent integrated development of all subsystems aligned to the end-user requirements. The requirements should be amended as the WUSAT-3 design iterates. A verification plan should be formulated, detailing how the CubeSat meets the specified requirements, either through detailed analysis or testing. Future teams should update budgets and margins as the design becomes finalised.

B. Technical Subsystem Development

WUSAT-3 2018-19 should aim to advance the CubeSat's subsystems by completing the following technical developments. The structure and configuration team should aim to manufacture and test the antenna deployment system to validate this year's findings and finalise the design, with an end goal of a fully operational deployment system on all four antenna arms.

Furthermore, the thermal subsystem team will need to build on the ESATAN-TMS thermal analysis model, and simulate the internal heat transfer effectively. Once a thermal design has been finalised, thermal vacuum cycling and thermal balancing tests must be undertaken to verify the thermal design meets the subsystems requirements.

Next year's ADCS team will need to evaluate the design requirements of the subsystem, make initial estimates for any missing information and design a rudimentary proof of concept for the ADCS. The team should also manufacture a rig to allow 3-dimensional testing of the control system using an air levitated bed. Through doing this, the detailed design of the subsystem can be developed such that by the end of the next stage the design is clear and specified. Future teams can then progress to specifying components or manufacturing elements of the design in-house.

For communications subsystem, the selected components will need to be tested and, after further work has been done on the data handling system and on the power budget, the system feasibility will need to be evaluated.

C. Project Realisation

For the aims and objectives of WUSAT-3 to be realised, a successful application to the European Space Agency's 'Fly your Satellite!' program must be achieved. Furthermore, the designs of each subsystem must be finalised, and the manufacture of the CubeSat carried out. Component and systems tests can then be completed, verifying the final designs. Providing University and sponsor support is maintained, WUSAT-3 should realistically achieve its aim to launch a direction-finding CubeSat within three years as a technology demonstrator.

V. Conclusions

Year 3 of the 6-year WUSAT-3 project to develop a Wildlife Monitoring CubeSat is making significant progress in the continued progression of the existing structure and configuration, mission analysis, power, and ADCS subsystems, while commencing work on the new communications, data handling, and thermal control subsystems.

This advancement can be accredited in part to the adoption of a Concurrent Systems Engineering approach to allow interacting subsystems to develop efficiently in parallel, aided by the invaluable experience gained by some team members' attendance at the ESA Concurrent Engineering challenge and CubeSat Concurrent Engineering Workshop.

Relevant stakeholders are in open communication with the team to clarify mission requirements defined through mission analysis, which are in the process of being met by the aforementioned work on various subsystems.

Finally, and most importantly for the primary goal of the project to act as part of the students' final year Masters accreditation; the university's formal learning objectives are being met as evidenced through first class feedback received for all assessed submissions to date.

ACKNOWLEDGMENTS

As a University project we are grateful for the assistance of; Roke Manor Research, SSTL, ESATAN-TMS, RS Components, Harwin, Andrew Little Fund, Proctor Group, and EuroCircuits for the support and assistance they provide during the CubeSat's design and development process.

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