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The CUAVA-1 CubeSat–A Pathfinder Satellite for Remote Sensing and Earth Observation

Xueliang Bai, Iver H. Cairns, Patrick Oppel, Youngho Eun, Anthony Monger, Christopher H. Betters, Sergio Leon-Saval, Joe Khachan, James Harpur
CUAVA, the ARC Training Centre for CubeSats, UAVS & Their Applications,
and School of Physics, The University of Sydney,
A28 Physics Rd, Camperdown NSW 2006, Australia; (+61) 430073666
x.bai@sydney.edu.au
Xiaofeng Wu, Yijun Huang, Byung Hoon Cho, Chung Hang Chu, Alex Gaoshan Lian, David Byrne, Flynn Bryant, Daniel Roger Hussey, Mitchell William Galletly, Ada Jiexin Song,
CUAVA and School of Aerospace, Mechanical and Mechatronic Engineering, University of Sydney,
Building J07, Darlington, NSW 2006, Australia
Andrew G. Dempster, Joon Wayn Cheong,
CUAVA and Australian Centre for Space Engineering Research (ACSER),
The University of New South Wales Sydney NSW 2052 Australia
Ediz Cetin, Tong Wu
CUAVA and School of Engineering, Macquarie University,
50 Waterloo Rd, Macquarie Park NSW 2113, Australia
Oliver Diessel,
School of Computer Science and Engineering,
The University of New South Wales, Sydney NSW 2052 Australia
Jason Held, Andreas Antoniades, Alix Murdoch, James Unicomb,
CUAVA and Saber Astronautics,
63-71 Balfour St, Chippendale NSW 2008 Australia
Paris Michaels
CUAVA and Air@wave Communications
Level 14, 309 Kent Street, Sydney NSW 2000, Australia

ABSTRACT

In this paper we report a 3U CubeSat named CUAVA-1 designed by the ARC Training Centre for CubeSats, UAVs, and Their Applications (CUAVA). CUAVA, funded by the Australian Research Council, aims to train students, develop new instruments and technology to solve crucial problems, and help develop a world-class Australian industry in CubeSats, UAVs, and related products. The CUAVA-1 project is the Centre's first CubeSat mission, following on from the 2 Australian satellites INSPIRE-2 and UNSW-EC0 CubeSats that launched in 2017. The mission is designed to serve as a precursor for a series of Earth observations missions and to demonstrate new technologies developed by our partners. We also intend to use the satellite to provide students hands-on experiences and to gain experience for our engineering, science and industry teams for future, more complex, missions.

Keywords: CubeSat, Imager, Spectrograph, GPS, High speed communication, Space weather, Earth observation

INTRODUCTION

The ARC Training Centre for CubeSats, UAVs, and Their Applications (CUAVA) (CUAVA, 2018) is funded by the Australian Research Council (ARC) and exists as a joint effort between the University of Sydney (USYD), The University of New South Wales (UNSW), Macquarie University (MQ), and multiple government laboratory and industry partners. The qualitative goals for CUAVA are to train the next generation of workers in cutting edge advanced manufacturing, entrepreneurship, and commercial space & UAV applications, develop new instruments, technology, and products to solve crucial problems, and to boost the development of the Australian industry in CubeSats, UAVs, and related products. CUAVA aims to fly 2-3 CubeSat missions and 5 UAV mission during the first 5-year period of the Centre. The objectives of CUAVA's flight programs are to train future engineers, industry people, and scientists in space and UAV applications and in commercialization, to increase the capabilities of CubeSats and UAVs, to solve particular research problems, to flight-test new applications and services, and to develop the future workforce of the space and UAV industries in Australia.

CUAVA-1 is the Centre's first satellite. It serves as a capability demonstration and payload design validation satellite and will be a precursor for a series of Earth observation missions. CUAVA-1 will carry 4 payloads designed and built by CUAVA partners: an Imager, Spectrograph, and TinyTol Instrument (ISTI) as a pathfinder towards a CubeSat-compatible hyperspectral imager (USYD); the GPS instrument to obtain position and velocity information and prepare us for the Centre's future reflectometry and radio occultation applications (UNSW); a radiation counter and data over power-bus payload to 1) measure space weather via high energy X-rays and gamma rays resulting from energetic particle impacts with the CubeSat; and 2) demonstrate a novel data over power-bus solution on a CubeSat (USYD); and an in-orbit reconfigurable Field Programmable Gate Array (FPGA) to demonstrate and validate new approaches to rapidly recovering from radiation induced Single Event Upsets (SEUs) with reconfigurable hardware (MQ and UNSW).

The launch provider for the CUAVA-1 satellite is the Japan Aerospace Exploration Agency (JAXA) via a Japanese company named SpaceBD Incorporation. With SpaceBD's help, the CUAVA-1 has completed space qualification tests and safety reviews and was integrated in the JEM Small Satellite Orbital Deployer (J-SSOD) (JAXA, n.d.) by JAXA on 21st May 2021 at JAXA's Tsukuba Space Center (TKSC). The satellite will then be shipped to the U.S. launch site, launched in August 2021 as a cargo re-supply mission to the International Space Station (ISS) and deployed from the Japanese Experiment Module (JEM). In this paper, we will first discuss the CUAVA-1 satellite and payload design and then focus on the challenges we have faced, and the lessons learnt. The Centre is also building another two satellites, namely CUAVA-2 and CUAVA-3, around next iterations of our hyperspectral imager and GPS-Reflectometry transceiver, respectively. These two satellites are scheduled to be delivered by late-2022.

MISSION OBJECTIVES

The main objectives of the CUAVA-1 satellite is to provide a satellite platform for the first-generation instruments/sensors for the future CUAVA Earth observations applications, which include:

I. ISTI (Imager, Spectrograph, and TinyTol Instrument) payload: Developed by a team in the school of physics at The University of Sydney. It contains a RGB camera (same spatial resolution as Landsat), hyperspectral spectrograph from Ocean sciences for image core, & TinyTol for Breakthrough Foundation;

II. Kea GPS receiver (UNSW): Measure the position and velocity and also a pathfinder mission for future radio reflectometry missions using GPS signal.

The secondary objectives are to make technical demonstrations and in-orbit experiments, which include:

III. the RC and DoP (Radiation Counter and Data over Power-bus) payload developed by a team at AMME in The University of Sydney. This payload is used to 1) measure space weather via high energy X-rays and gamma rays resulting from energetic particle impacts with CubeSat; 2) Demonstrate a novel Data over Power-bus solution on a CubeSat;

IV. the RUSH (Reconfigurable Systems for Space) payload, which aims to demonstrate an in-orbit reconfigurable FPGA system that will enable FPGA based off-the shelf hardware to be customized for this use without compromising reliability.

In addition to these scientific objectives, as the Centre's first CubeSat mission, we also aim to train our postdoctoral fellows and post/under-graduate students to gain experience and confidence during the development process, and to build the Centre's track record. Also, the media exposure and hopefully, success of CUAVA-1 will further the public interest in space in Australia, as well as increase the probability of further funding into the industry to propel Australia's and the universities' space capabilities, all while partnering with commercial entities.

CUAVA-1 DESIGN OVERVIEW

CUAVA-1 satellite carries significant heritage from the QB50 CubeSats: INSPIRE-2 (USYD QB50 Team, 2017) and UNSW-ECO (UNSW QB50 Team, 2017) (Cheong, et al., 2020). Payload mounting structures are designed to accommodate the Size, Weight and Power (SWaP) requirements of the 3U CubeSat platform. The internal layout of the CUAVA-1 satellite is illustrated in Figure 1:

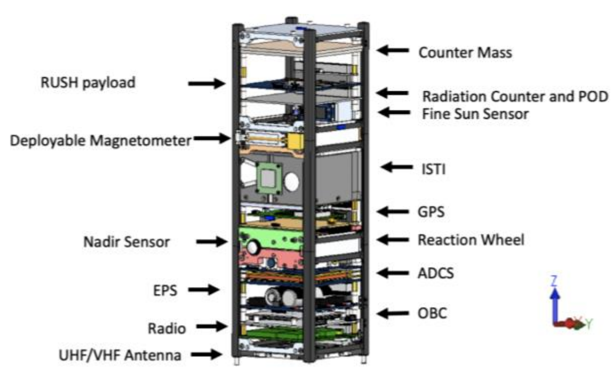

Figure 1: CUAVA-1 satellite with labels of subsystems and solar panels removed

The CUAVA-1 satellite has 9 body-mounted solar panels (7 from GomSpace and 2 experimental ones from industry partner Air@wave Communications). A deployable UHF/VHF antenna is mounted at the -Z end of the satellite. The GPS antenna, ISTI lens, fine sun-sensor and nadir sensors are exposed outside of the satellite to perform desired measurements. The exterior view for the fully integrated satellite is shown in Figure 2:

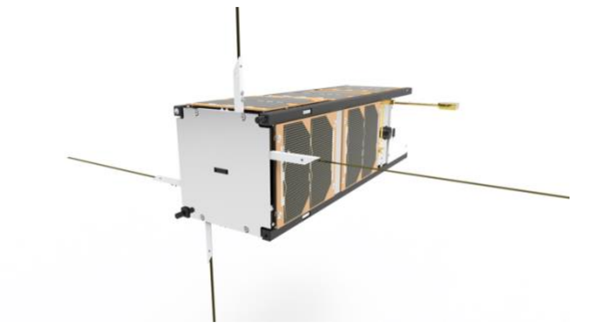

Figure 2: Render of the exterior view of the CUAVA-1 satellite, with the antenna and external magnetometer deployed

CUAVA-1 BUS DESIGN

The satellite bus includes an ISIS 3U CubeSat structure. The satellite bus is mainly designed using commercial-off-the-shelf (COTS) products as listed in Table 1.

Table 1: CUAVA-1 satellite bus components

Subsystems/Functional components	Component Description
On-board controller (OBC)	ISIS iOBC Onboard computer
Full duplex UHF/VHF transceiver	ISIS.TrxVU full duplex radio
Deployable VHF/ UHF antenna system	ISIS.deployable antenna system
Electrical power system (EPS) and battery pack	NanoPower P31us with 2 battery pack
Battery cell	Panasonic Lithium Ion 18650 cell
Solar Panels	GomSpace (7 pieces) and Air@wave (2 pieces)
Solar Cells (integrated onto above)	AzurSpace 3G-18 space qualified solar cells
Flight Preparation Panel and debug interface panel	In-house designed
Attitude Determination and Control system (ADCS)	CubeSpace CubeADCS
On-board controller (OBC)	ISIS ((ISIS), 2016) 3U CubeSat Structure with custom modifications for ISS launch

The ISIS on-board controller is a 400MHz, 32-bit ARM9 CPU with 32MB SDRAM and 2x 2GB SD-card for housekeeping and data handling. We use a full-duplex ISIS VHF and UHF transceiver combined with deployable antennas used for uplink and downlink respectively. The CubeSpace ADCS has a Y-momentum wheel, 3 magnetorquers, 6 coarse sun sensors, 1 fine sensor and 1 earth sensors. It is used for 3-axis stabilisation, detumbling and attitude control.

The power system sizing is based on the INSPIRE-2 mission due to the similar power consumption for the major payloads. 7 pairs of space qualified solar panels are used, which can provide on average 2.5Whr energy gain each (ISS) orbit. In addition, 2 experimental solar panels from an Australian supplier Air@wave communication is used to in-orbit validate these products. The GOMspace Nanopower EPS (with 2 lithium ion 18650 battery cells and 3.75 Whr maximum depth of discharge) is used as the power subsystem for the satellite. The EPS has 2 permanent 3.3V channels and 2 permanent 5V channels and 6 controllable power channels (3 x 3.3V and 3 x 5V). A system diagram of CUAVA-1 is shown in Figure 3.

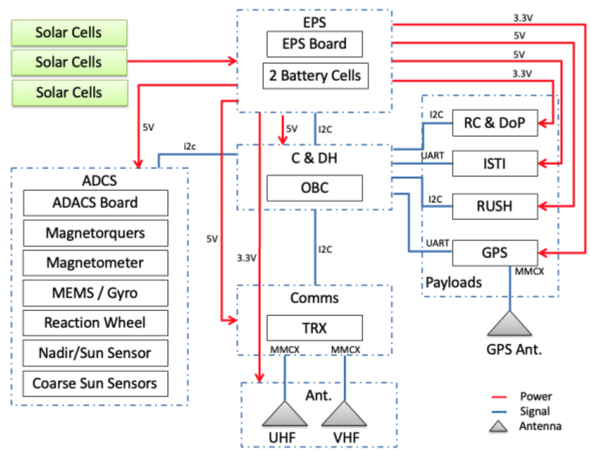

Figure 3: CUAVA-1 system diagram

SOFTWARE DESIGN

The flight software was developed in-house by the CUAVA-1 software team based on an open source platform named KubOS (Kubos, n.d.). KubOS is a package framework that runs directly on satellite hardware combining a customized Linux distribution, subsystem APIs, and core services. It provides some of the core functions for satellite developers such as File Transfer Protocol, mission scheduler etc. Based on the Kubos platform, the CUAVA team has developed the Application Programming Interfaces (APIs) and Services for the ISIS UHF/VHF radio, GomSpace NanoPower EPS, CubeADCS, shell commands and all of our payloads. We have also developed the mission applications for the antenna deployment, beaconing and telemetry and ADCS commissioning and pointing. The software was fully tested functionally and then over a 4-

week CONOP test campaign after the satellite was fully integrated.

The CUAVA team intends to open source the CUAVA-1 specific software and an independent fork of the Kubos framework after validation in orbit. The fork will be rebranded as CubeOS to distinguish it from the original repository and fulfil the Kubos Apache 2.0 licence requirements. The CUAVA team is committed to maintaining and improving CubeOS for the duration of the training centre, and hopefully beyond.

PAYLOAD DESIGN

Imager, Spectrograph, and TinyTol Instrument (ISTI)

The CUAVA-1 ISTI instrument (Figures 4 and 5) is intended to be a first step to a full CubeSat-ready hyperspectral imager and also fly the independent TinyTol instrument. The current concept for the former is to merge a simple imager and a fibre bundle integral field unit (IFU) so as to simultaneously capture, first, a high-resolution RGB image (10-20 m spatial resolution) using a standard CMOS RGB sensor and, second, a hyperspectral image with very good to moderate spectral resolution (1-20 nm) and a coarser spatial sampling (50-100m). Using this hybrid photonic technique allows us to re-balance some of the trade-offs traditionally required, enabling increased light collection ability for a given size and spectral resolution than previously possible. The result is increased throughput (and thus signal-to-noise), particularly at high (for hyperspectral imaging) spectral resolutions. In this first version on CUAVA-1, the fibre bundle IFU is replaced by a single optical fibre connected to a COTS Ocean Optics spectrograph. This optical fibre will allow measurement of the spectrum for the central 50-100 m radius region of the RGB image. The next version is envisaged to have a full IFU and fly on CUAVA-2 and probably a UAV mission.

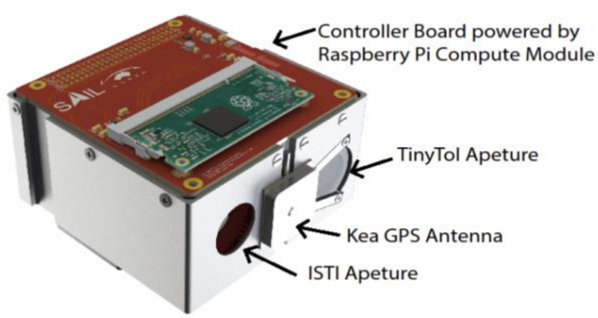

Figure 4: Render of the mechanical structure of ISTI

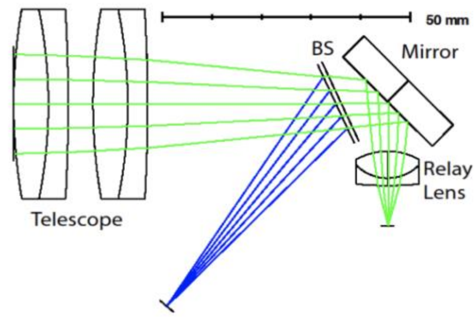

Figure 5: The optical layout of the imager (blue path), showing a beam splitter (BS) system that enables some light to be collected by an optical fibre (bundle; green path)).

A secondary payload incorporated in the ISTI housing is the TinyTol telescope. This device will demonstrate a cutting-edge astrometry technique for the first time in space. It is a pathfinder for a larger independent satellite mission, Toliman, to study the Alpha Centauri star system as part of the Breakthrough Watch program (Breakthrough Initiatives, 2019). More information on the Toliman Concept can be found in Ref. (Tuthill, et al.).

The block diagram for the ISTI is shown in Figure 6.

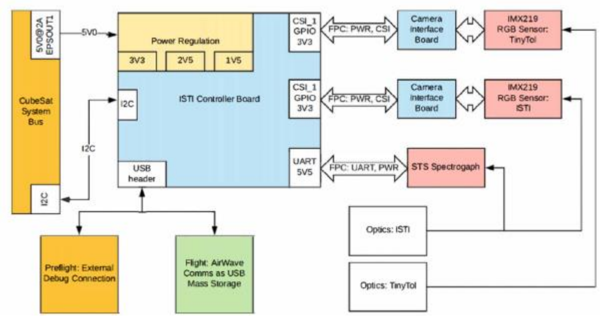

Figure 6:Block Diagram of the ISTI package, including the RGB imager, spectrograph, and TinyTol instruments.

GPS payload

The GPS payload (Figure 7) comprises a Namuru Kea GPS receiver (ACSER, 2017) and an interfacing daughter board, which permits the receiver to be interfaced into the CubeSat Stack Connector. A GPS antenna is mounted on the external body of the spacecraft. The antenna will be zenith facing during nominal operation for optimal reception. An active patch antenna with built-in Low Noise Amplifier (LNA) will be employed to deliver the necessary gain.

Figure 7 Kea GPS receiver

The Kea GPS hardware has one main objective, that is to validate its provision of precise navigation/positioning information via GPS L1 signals received in LEO. Its secondary objectives are: (1) to be able to provide precise navigation/positioning information at its end-of-life to characterise its trajectory in a decaying orbit, and (2) to be able to collect raw signal data for analysis while the spacecraft is tumbling (or in an unstable ADCS state) and while it is stable (for the prototyping of future GNSS-R Kea receivers).

When operating in continuous operation with 1 Hz measurement and navigation output, the receiver generates approximately 116,824 bytes per minute, which is equivalent to 1,947 bytes/sec or 15,576 bps. However, this data is formatted as NMEA ASCII messages and is very inefficient in its representation. There are several mechanisms that might be employed in order to reduce this output rate. We are storing the full set of data in the standard output format but could then batch compress the data on the OBC. This would allow firmware modifications to be avoided and may also be beneficial for other payloads having the same problem. In order to estimate the amount of compression that may be expected on default output from the receiver, a 6.83 MB output file captured from a Namuru being operated in a Spirent G6560 space scenario was compressed using WinZip. The compressed file was 1.65 MB in size, indicating a compression factor of 4.13 in this case. For this test data set, this would be equivalent to a compressed data rate of 3,770 bps, which is within the bandwidth of the 9,600 bps UHF radio. Hence, we may be able to obtain near real-time NMEA data from Kea as CUAVA-1 makes its passes over the ground station.

Radiation Counter and Data over Power-bus (RC & DoP) Payload

1) The Radiation Counter payload:

The Radiation Counter (RC) payload (Figure 8) is designed to study the space weather and the radiation effect for LEO satellites. Selected base on the INSPIRE-2 heritage (Cairns, et al., 2020), solid-state BG51SM radiation detectors are used to detect both beta and gamma radiation, including X-rays. The detection element within this integrated circuit is a cluster of PIN diodes. Other circuitry enables a TTL output pulse to be given out once a photon or beta particle has been detected. The circuitry that produces the TTL pulse has a threshold that is temperature-compensated in order to provide a reliable and consistent pulse output. A typical power consumption for each detector is approximately 83 μW. There will be 5 of these units to increase the sensitivity to radiation, which requires 0.25 mW in nominal operation.

The sensitivity to radiation for each unit is 5 pulses per minute for a 1 microSievert per hour radiation dose. On Earth's surface the natural radiation dose level is approximately 0.1 microSievert per hour, which means 2 pulses per minute with 5 units of BG51SM operating at the same time. In Low Earth Orbit (LEO), the radiation dose levels may be up to two orders of magnitude greater, which means the pulse output rate is expected to be approximately 200 pulses per minute.

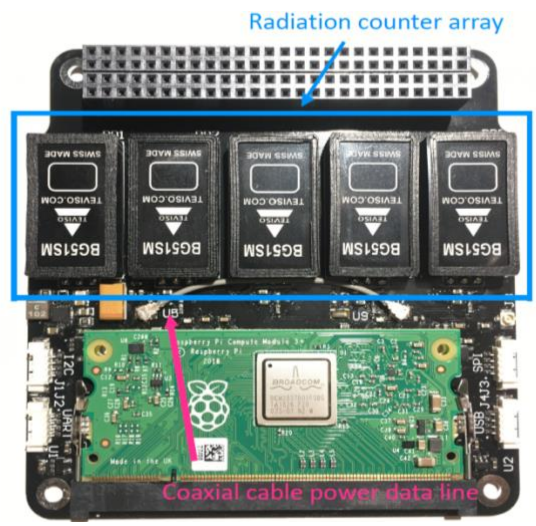

Figure 8: Radiation Counter and Data over Power-bus Payload (the Raspberry pi shown in the picture is only used for ground testing and not for flight)

2) The Data over Power-bus system:

The Data over Power-bus (DoP) system contains two data nodes. Each data node contains a switchable regulator and a demodulator. Data will be carried on the power transmission line and demodulated via a coaxial cable as shown in Figure 8. The block diagram of the DoP system is shown in Figure 9.

The Radiation Counter data is first collected by data node 1 and then modulated and injected into the power bus and transferred to data node 2 via the coaxial cable. The DoP system demonstrated in CUAVA-1 consumes

70mA@3.3V per node when transmitting, and < 1mA/node when idle. The speed for the DoP is tested to be 47MBs/second.

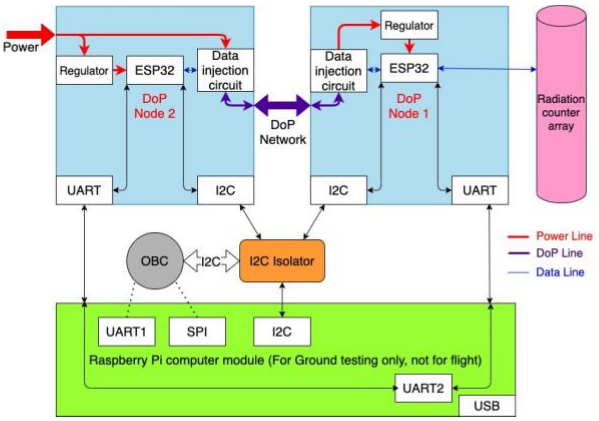

Figure 9 Block diagram for the Data over Power-bus (DoP) system

In future works, the DoP system can be integrated with communication protocols such as UART, CAN, or I2C to greatly reduce the number of cables used on a CubeSat.

Reconfigurable Systems for Space (RUSH) Payload

The RUSH payload comprises a custom FPGA-based board (Figures 10) and special-purpose 'firmware' designed to assess the prevalence of and recovery from radiation induced SEUs.

Figure 10 the RUSH payload

The primary objective of the RUSH payload is to demonstrate and validate new approaches to rapidly recover from SEUs in commercial, SRAM-based FPGA devices (Cetin, et al., 2016). As it can be observed from Figure 11, at the heart of the RUSH payload is the Xilinx Artix-7 XC7A200T FPGA, chosen for its high logic density to power consumption ratio, and the Microsemi SmartFusion 2 System-On-Chip (SoC) Microcontroller Unit (MCU), which oversees the overall operation of the payload and acts as an interface between the FPGA and the CubeSat OBC. The payload was designed and built to compare the performance of module– and scrubbing–based approaches to SEU recovery. During the experiment SEU events will be logged by the MCU and the time, location, and time to recover will be transmitted to Earth as CUAVA-1 makes its passes over the ground station.

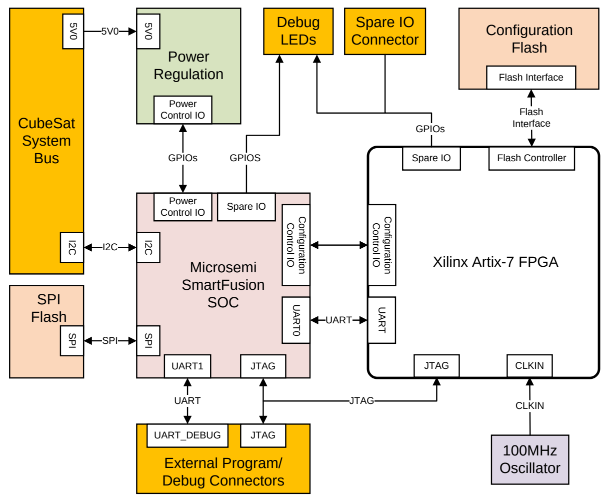

Figure 11 Block diagram of RUSH payload board

INTEGRATION AND TESTING

The CUAVA-1 satellite was first integrated in September 2020. Due to unexpected delays on some of the payload development, the time planned for integration was shortened significantly. During the fit check, we noticed the satellite didn't go into the fit check case smoothly enough. Limited by the measuring equipment and experience, we only measured the dimensions of the satellite and ensured these measurements were within the allowed tolerance (+/- 0.1mm). Due to the pressing deadline and some miscommunication with SpaceBD/JAXA, the team proceeded with the environmental testing without sufficiently measuring the perpendicularity and parallelism of the structure.

Both the vibration test and thermal vacuum were performed at the Advanced Instrumentation and Technology Centre (AITC) in Canberra, Australia. The vibration test was done at 6.81 grms, as requested by Space/JAXA. The thermal vacuum test is not required by the launch provider but was performed to test the thermal performance of the satellite as one of our internal test goals. Four thermal cycles were performed between -10 ºC and 40 ºC, including 4 hours of cold soaking and 4 hours of hot soaking. The satellite was remained on during the entire thermal cycling test. The payloads were switched on and tested sequentially with temperature monitored. An antenna deployment test was also done successfully at -10 ºC. Figure 12 shows the CUAVA-1 satellite during the environmental testing.

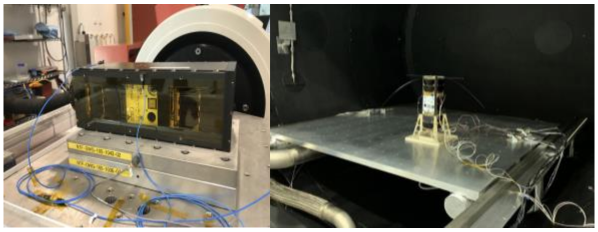

Figure 12 Environmental test for CUAVA-1

The visual inspection and functional tests after the environmental tests concluded that this round of testing was a success. However, later during the safety review process, the JAXA team pointed out that there were scratches on the deployment rails (Figure 13) and suspected there maybe dimensional issues with the satellite structure.

Figure 13 Scratches on the satellite rail

JAXA therefore requested the CUAVA team to perform a coordinate measuring machine (CMM) test for the outer dimensions of the satellite. The setup of the CMM test is shown in Figure 14. The measurement origin was set to be the corner between surfaces 1 and 2 on the +Z side of the satellite.

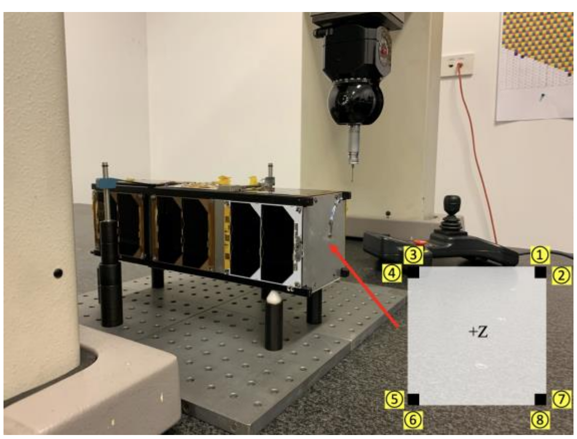

Figure 14 CMM test setup

The data shown in Figure 15 are distances between individual measurement points to the constructed plane using average measurement values from the opposite side. The tolerance required by JAXA is ± 0.1mm for the dimensions and ± 0.2mm for perpendicularity and parallelism. Initial analysis of the CMM measurement suggested some parts of the satellite were quite close to the allowed tolerance (in particular between surface 1 and surface 8 marked in Figure 14). The dimensional violation was not significant (within 20% of the allowed tolerance) and maybe was negotiable with the launch provider (JAXA).

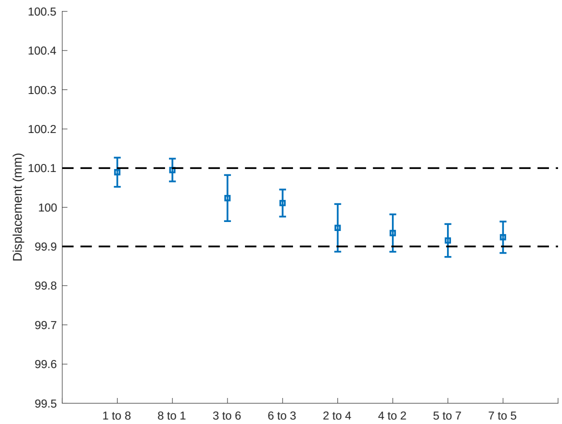

Figure 15 CMM displacement measurement

However, further study of the CMM data revealed bigger issues with the satellite. As shown in Figure 16, viewing from the +Z side of the satellite, relative to the measurement origin, each of the other 3 corners deviated from the allowed envelope. For example, the *x* axes of the bottom 2 figures were 0.700mm and 0.573mm shifted to the right, even though the distance between these 2 surfaces (100.127mm) was still close to 100mm $\pm$ 0.1mm. Although these corners are only projected values and may not accurately reflect the actual structure shape, it was clear that both the perpendicularity and the parallelism of the satellite structure failed JAXA's requirements and a re-integration was necessary.

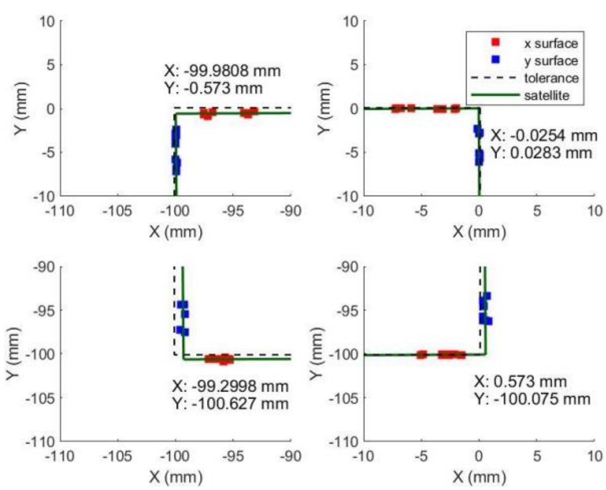

Figure 16 Distortion observed using CMM measurements

We examined the satellite structure while dissembling the satellite, and believed the issues were mainly caused by inadequate tolerance control for the in-house design structures. All individual parts were designed with ± 0.1mm tolerance and these deviations built up and affected the perpendicularity and parallelism of the satellite structure. The team then took a more careful measurement approach during the re-integration, which includes:

1) Starting the integration on a demonstrably flat surface (granite table and a set of horizontal jigs with < 5 μm tolerance)
2) Measuring the flatness of the rail using a vertical dial with 5 μm accuracy,
3) Measuring the parallelism for each surface with the feeler gauges,
4) Measuring the perpendicularity for each junction rail surface using engineering square.

The measurement methods are shown in Figure 17 and the dimensional measurements are summarized in Figure 18. Comparing with Figure 15, all measurements are within the allowed tolerance. The parallelism and perpendicularity are validated to be below 0.1mm using the feeler gauge and engineering square. Fit check test after the second integration was much smoother than the previous tests. Combined the measurements and the fit check result, we concluded that the quality of this round of integration was much better than before.

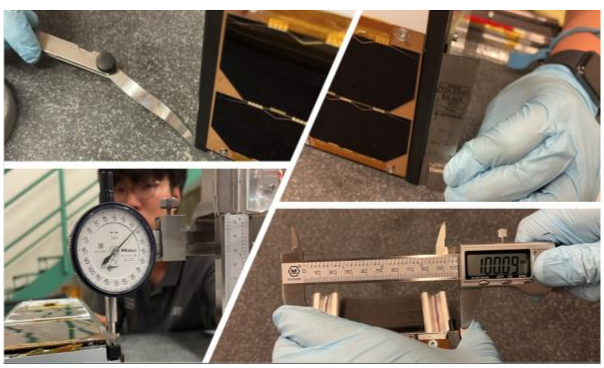

Figure 17 Dimensional measurements during re-integration

After the re-integration, we performed environmental testing again in AITC and successfully passed the safety review required by SpaceBD/JAXA. Figure 19 shows the CUAVA-1 satellite after the second round of environmental testing at AITC.

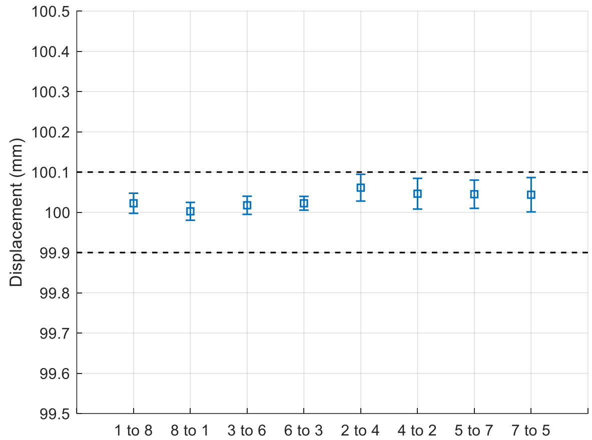

Figure 18 CUAVA-1 Final integration

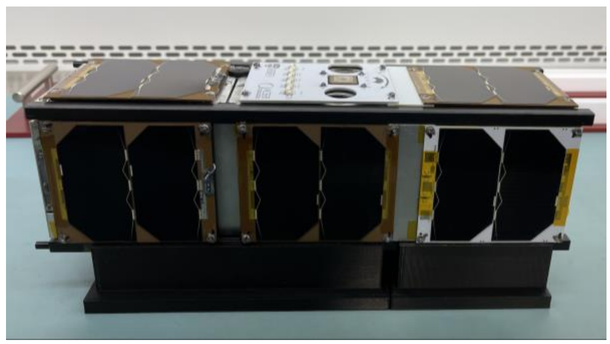

Figure 19 CUAVA-1 after final integration and environmental testing

CONCEPT of operation

Figure 20 shows a flow diagram for the Concept of Operation (CONOP) for CUAVA-1. The satellite will be in its off state while stowed in the deployer at ISS. Once deployed into space, the kill switches will be released to begin the process of turning on the satellite. The satellite will initiate the 'ON' sequence 30 minutes after deployment. This will begin turning on the main bus components and the Radiation Counter payload, starting housekeeping on each component. The OBC will then deploy the deployable UHF and VHF antennas.

Ten minutes after the antenna deployment, the satellite will start to transmit housekeeping beacon data to the CUAVA ground station and ground stations of international radio amateurs. This data is to confirm that the satellite is working and collect high-level summaries of the system data and payload data stored in the multi-frame beacon signals. Putting the (Radiation Counter) payload summary data into the beacon signals is one

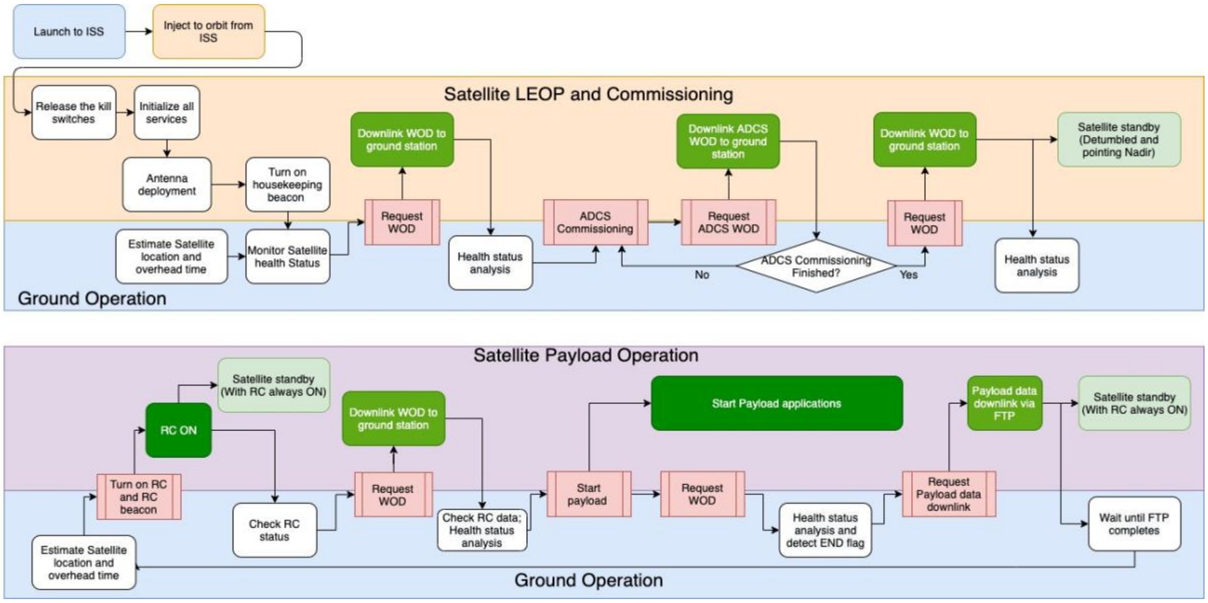

Figure 20 CUAVA-1 CONOP Flow Diagram

lesson learned from the INSPIRE-2 mission (Cairns, et al., 2020) to ensure the minimum level of mission success can be achieved.

Once communications are established with the ground, the ground operator will enable the satellite's ADCS system and begin its detumbling phase by initiating what is known as the acquisition mode in the CubeADCS package. This will make use of the magnetorquers, magnetometers, and the Sun and Earth sensors to dump all angular momentum to the pitch axis, and achieve Y-Thomson Spin at -2deg/s. For payload operation (GPS and ISTI) with pointing requirements, the satellite can use the single reaction wheel system to orient the instruments to the nadir/zenith direction. Once the science measurements are completed, the data will be saved to the OBC and then downlinked to the ground station using the file transfer protocol (FTP) service.

GROUND STATION DESIGN

The UHF/VHF ground station for CUAVA-1 is being designed in-house by the CUAVA team. A crossed Yagi antenna set is used for both 2 m (uplink) and 70 cm (downlink) bands, controlled by a set of rotors. All ground stations will be operated in the amateur radio bands and the coordination request was approved by the International Amateur Radio Union.

A Software Defined Radio (SDR) based on a bladeRF 2.0 micro xA4 is used for receiving and transmitting radio signals. The SDR and the mission control software are being developed as a joint effort between CUAVA and its corporate partner Saber Astronautics (Saber). The radio link uses binary phase shift keying (BPSK) and frequency shift keying (FSK) for downlink and uplink respectively. The baud rate on both channels is 9600 bps. Modulation and demodulation are done in software using GNURadio. An open source (downlink only) GNURadio flowgraph (Figure 21) will be provided to the public for crowd-sourced beacon information.

A Python3 based command-line interface tool was developed to assist the development and testing of the ground station and satellite interface. An interactive menu system is designed for users to issue single telecommands. Batches of commands can also be executed in sequence, with wait-for-response times, and the number of retries optionally specified for each command. Timestamps can be injected into commands during run time to enable clock synchronizations, and more complex command arguments such as TLE read in from files.

The network and data-link layers utilized the CCSDS Space Packet Protocol and AX.25 framing, respectively. The CUAVA-1 OBC hosts individual APIs and services for each subsystem on their own ports. The telecommands will be routed to dedicated ports using the Space Packet Protocol. Command encoding packetization and framing can be performed in real time using the command line tool.

During flight, the satellite is expected to be operated jointly across facilities in Sydney and the Responsive Space Operations Centre in Adelaide designed and operated by our ground operation partner Saber Astronautics. Saber's Predictive-Interactive-Groundstation-Interface (PIGI) will be used as operations software during the mission. PIGI uses a user-friendly graphical interface to interface with Saber's infrastructure layer for commanding, telemetry analysis,

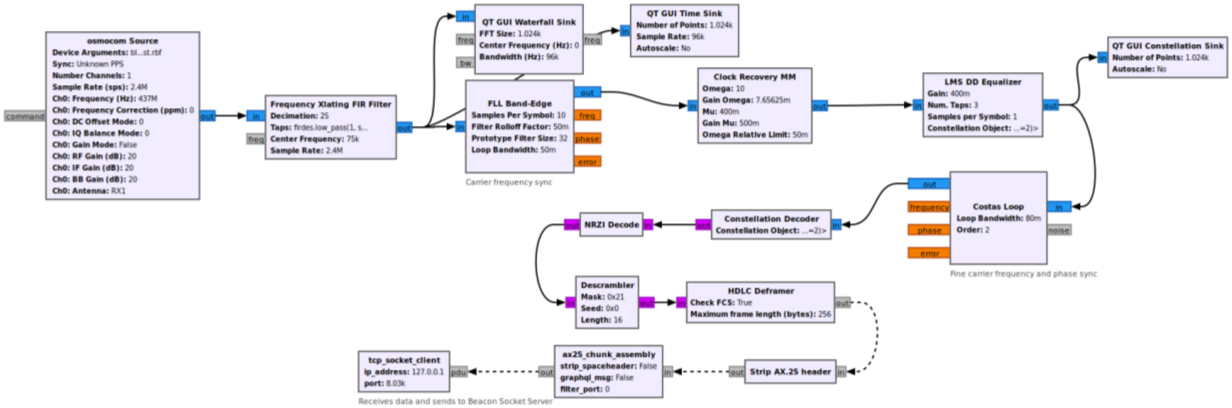

Figure 21 GNUradio flowchart (downlink only)

linking to the ground station, and communicating with the satellite.

CONCLUSION AND FUTURE MISSIONS

CUAVA-1 is a pathfinder mission designed to test, validate and demonstrate instruments developed by CUAVA and its partners. It is also important for us to train students and gain experience for the team. During the CUAVA-1 project, we have involved 26 students in the project. We have also integrated the CUAVA team with all its partner and prepared ourselves for future more complex missions.

With the completion of the CUAVA-1 satellite, we have started the CUAVA-2 and CUAVA-3 satellite design, which have similar bus systems to CUAVA-1 but with improved payloads and upgraded ADCS and high-speed communication system. The current confirmed payloads include a fully photonic hyperspectral imager with wider spectral range and a GPS used to measure GPS signals scattered off the sea to determine the sea state remotely. The CUAVA-2 launch is planned for late 2021 to early 2022.

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