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CONTENTCUBE: A 1U CUBESAT TO TEST DISPLAY SCREENS IN SPACE

AUTHORS

Joseph Esser, Jason Jagoda, Steffen Winther, Timothy McEvoy, Tejas Vinod, Larsen VanOfferen, Dylan Cooper, Dr. Kevin Schroeder
inspireFly at Virginia Tech
239 Old Cedarfield Drive, Blacksburg, VA, 24060; 240-671-5313
joeesser@vt.edu

ABSTRACT

ContentCube is a novel 1U CubeSat developed by inspireFly at Virginia Polytechnic and State University, in collaboration with Bronco Space at Cal Poly Pomona. The mission of ContentCube is to test the performance of the Adafruit breakout board OLED screen in orbit. This mission could pave the way for using display screens in the space environment. Such applications could include astronauts having displays on their suits that they can use to monitor critical information, or robotic systems having complex digital displays. The external display screen will be tested through a novel payload designed and tested at Virginia Tech. This payload utilizes an Arducam Mega camera, and a mirror attached to a deployable boom to take a picture of the display screen. The mission will be considered a success if a picture of the working display screen is transmitted back to Earth. In addition to this novel payload, ContentCube will be the first test by an outside university of Bronco Space's PROVES Kit, a 1U satellite bus designed to be easily modified by other universities for their own use. This multi-university effort will test the viability of payload modifications to PROVES to see if it is a suitable platform to accelerate satellite development at universities.

INTRODUCTION

inspireFly is a CubeSat team founded in 2018 at Virginia Polytechnic and State University. InspireFly consists of undergraduate students studying a range of engineering disciplines. These mainly include aerospace, mechanical, electrical and computer engineering majors. The vision for the team's first mission was to create a way for people to interact with space on a personal level. This was going to be achieved by a CubeSat, named ContentCube, equipped with a liquid crystal display (LCD) screen and camera attached to a boom arm to achieve a "selfie-like" image. An image would be transmitted from a ground station up to the satellite, then that image would be projected onto the LCD screen on the satellite. Next, the camera on the boom arm would capture a picture of the display screen, with Earth in the background. If the image uplinked to the satellite was of a person, that person would receive a picture of themselves in space. The purpose of this was to inspire the public about space exploration by allowing them to be directly involved in a satellite mission. This initial mission proposal was submitted to the SEDS SAT-II national space exploration competition. The team won first place, with the prize being a fully funded launch.[1,2] In addition to winning this competition, the team presented at the 5th International Academy of Astronautics conference in January 2020, and at Paris Space Week in March 2020. All these presentations attracted a lot of financial interest, leading to an initial budget of over $100,000 dollars. The plan was to buy a commercial CubeSat and integrate the payload, consisting of the boom arm, camera, LCD screen, and a circuit board, into it. However, due to the COVID-19 pandemic, all these funding avenues vanished rapidly, leaving behind a student team with a plan that required $100,000. The team stagnated as they tried to salvage the initial plan, and the restrictions imposed by COVID meant no hands-on engineering work could be done. This all led to the team nearly dissolving during the 2020-2021 academic year. Despite the lack of progress and uncertainty on how to proceed, the team persisted and tried to salvage the project. From 2021-2022, the plan shifted to purchasing the KRATOS bus from the Ecuadorian Space Agency for $47,000. In addition, work began on designing the payload for the mission by testing various cameras and screens. Then during the 2022-2023 academic year, the plan once again shifted to utilizing the open-source design for the FloripaSat1 mission, conducted by FloripaSat at the Federal University of Santa Catarina. Continued research was being done into choosing a camera and display screen, however due to poor documentation, none of the knowledge about screens and cameras generated during the 2021-2022 academic year was retained. However, the team did make a move to switch from an LCD screen to an OLED screen. This decision was made as the price of OLED screens had dropped significantly, making them more practical. Finally, during the summer of 2023, the mission underwent its final major design overhaul. The team decided to purchase the PROVES Kit from Bronco Space - a preassembled, CubeSat Platform, based off the successfully flown Yearling CubeSat.[3] The best part of the PROVES Kit was its price. At only $5000, it was significantly cheaper than any other commercial option. This kit provided all the necessary hardware, software, and engineering support needed to lay the foundation for the ContentCube mission. This decision, along with a revamped team structure full of dedicated team members, allowed inspireFly to make rapid progress during the 2023-2024 academic year.

Despite obtaining the PROVES Kit, several engineering challenges persisted. The first major challenge was redesigning the antenna system. The PROVES Kit featured a bent dipole antenna, constructed using a tape measure, operating in the 433MHZ amateur band. Thanks to efforts from years prior, the inspireFly team acquired the EnduroSat 1U UHF antenna, which had better performance metrics than the antenna used by the PROVES Kit. Therefore, the PROVES Kit communications board, which included the antenna and radio, will be stripped of the antenna, and moved from being on the -Z face to being in the internal stack of the CubeSat. The -Z face will instead house only the EnduroSat antenna. The +Z face also had to be redesigned. On the PROVES Kit, the +Z face is used for surface mounted solar panels. However, due to the payload board featuring a boom arm, the payload board had to go on the +Z face. The positioning of these boards can be seen in Figure 1.

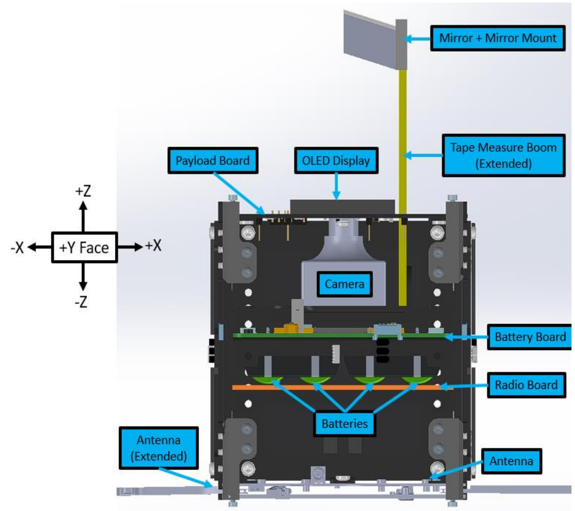

Figure 1: 3D Model of ContentCube

These two modifications to the PROVES Kit, although necessary, introduced major risks to the success of the ContentCube mission. Due to the implementation of a new antenna and payload board, on the -Z and +Z faces respectively, there is a risk that the CubeSat could orient itself so that a Z face is always directly facing the sun. This would limit the power generation of ContentCube, increasing the chance for mission failure. The second major risk is the design modifications remove the satellite's ability to orient itself. The PROVES kit features imbedded magnetorquers in all its solar panels. By replacing the -Z face with the Endurosat antenna, and the +Z face with the payload, the ability to stabilize the satellite in 3 axis is lost. This effectively removes the satellite's ability to orient the camera in a specific direction to ensure Earth is in the background of the image.

During the 2023-2024 academic year, inspireFly was broken up into multiple sub-teams, each contributing to the overall mission success. The Mechanical Systems Sub-Team was responsible for the boom deployment and camera housing. The Mission Operations Sub-Team was responsible for high level simulations and camera testing, The Payload and Electronics Sub-team was responsible for designing the payload board and calculating the power budget. The Software Sub-Team was responsible for assisting both Mission Ops and Payload and Electronics with coding needs. Lastly, the Communications Sub-Team was responsible for designing a link budget, data packet protocol, and upgrading the Virginia Tech Ground Station so that it is compatible with the mission.[4]

PAYLOAD DESIGN

Electronics and PCB

The first item the Payload and Electronics (P&E) Sub-Team needed to decide on was what microcontroller they were going to use. Mainly, it was between a Raspberry Pi, or an Arduino based platform. Many of the camera peripherals for this type of application have preexisting libraries for Arduino, however the PROVES Kit uses the RP2040 microcontroller, which is a Raspberry Pi chip. While it made programming for peripherals more difficult, interfacing with the Bronco Space satellite platform was a higher priority. Therefore, the team chose a Raspberry Pi RP2040 microcontroller to serve as the payload control. After this decision was made, the supporting infrastructure around the RP2040 was integrated into the design.

The supporting infrastructure for the RP2040 consisted of a 12 MHz oscillator, 128 Mbit QSPI (quad serial peripheral interface) flash storage, micro-USB interface, various decoupling capacitors and two switches for resetting and selecting the boot interface for the microcontroller. Along with this, a 3.3V linear voltage regulator was placed between the micro-USB 5V VBUS pin to facilitate powering of the board for testing and programming. Adjacent to the voltage regulator are two LEDs used as indicators for 5V and 3.3V levels. All these aspects are defined in the open-source microcontroller applications documentation provided by Raspberry Pi.[5]

From here more application-specific decisions needed to be made, such as the communication protocols between the RP2040, Adafruit display, Arducam 3MP camera, and flight controller board. Using the documentation for both the display and camera, the choice of the primary communication protocol being SPI (serial peripheral interface) was easy, as both devices supported this as their primary protocol. Additionally, UART (universal asynchronous receiver / transmitter) was chosen to communicate between the payload board and the flight controller board due to various reasons. The first of these was due to the selection of remaining available channels on both the flight controller and payload RP2040s. Another important consideration was their positioning, where UART channel 0 is exposed in a corner of the footprint, which is away from other congested areas of the board. Lastly, UART was chosen as it is fundamentally an asynchronous protocol, so less communication errors between the two boards are expected.

While in space, there is no simple way to determine if a peripheral device is working as anticipated or not. Likewise, there is no way to tell why a peripheral device might not be working. These aspects drove the decision to integrate health monitoring circuitry into the payload board design. Since the RP2040 has its own internal health monitoring system, only two more were needed, one for the display and one for the camera. Chosen in this role was a current sense amplifier, specifically the Texas Instruments INA180A3IDBVR, measuring across a 0.065-ohm resistor. This resistor was selected by an equation provided in Texas Instruments' documentation, allowing the team to retain optimal accuracy when measuring by the RP2040. Both current sense amplifiers are connected back to the RP2040 via ADC (analog-to-digital converter) channels 0 and 1.

Aside from the health monitoring system, another design decision was made to ensure the functionality of the payload electronics. This was the inclusion of an Analog Devices Inc. MAX706RESA+T watchdog timer. Much like the RP2040 decision, this timer was chosen since it was already present on the Bronco Space flight controller board. By utilizing this component, the team simplified their design complexity, thanks to the open-source nature of the PROVES Kit.

The boom arm deployment system is on the same face as the payload board, and because of this, a method for releasing the boom arm needed to be included in the payload board's design. The payload board will feature a burn wire circuit, that when activated will burn a nichrome wire. Once this wire is cut through, the mirror boom arm will elastically spring forward.

To accommodate testing and validation of the manufactured payload boards, an additional LED is attached to one of the RP2040's remaining open GPIO (general purpose input/output) pins. This means a simple program can be used to validate proper operation of the RP2040's internal functionality. If necessary, provisions were made to connect the Raspberry Pi debugging probe to the system, which interfaces with the software-level debugging system within the RP2040 microcontroller. This would be used primarily in the case of inconsistent behavior from the microcontroller, providing the ability to see and interrupt every action taken internally by the microcontroller. The PCB also contains probe points throughout the board. These are used to check for shorted components before connecting to power, and to verify correct voltage levels once power is applied.

The physical PCB design itself is derived from the PROVES Kit flight controller board. This is primarily to ensure the physical fitment of the payload board to the PROVES Kit chassis. The PCB is a 4-layer stack-up, with layers 1 and 4 being ground/power plane filled, while layers 2 and 3 are reserved for signals. A common design practice was employed for non-Earth grounded boards, called “via stitching”. This is where a spaced-out pattern of vias is used to attach all the ground planes across the various layers together. This is because with enough vias, the different ground planes become indistinguishable from each other, preventing differing reference voltage levels. Another benefit of this is that the copper within each layer will have less of a thermal deviation, mitigating physical warping or damage.

One challenge faced in the design of the payload board system was size constraints. The 1U structure is mostly occupied by the outer structure, solar panels, and other PCBs. To solve this issue, an approach where PCB cutouts were made was chosen. This meant that certain payload elements would be stored inside the CubeSat and extend out through cutouts in the top face payload board. Multiple revisions of this approach were made. One such revision is shown in Figure 2. The revision shown includes cutouts for the camera and mirror boom arm. The eventual goal is to design the electronics such that the display screen, camera, and mirror all have cutouts.

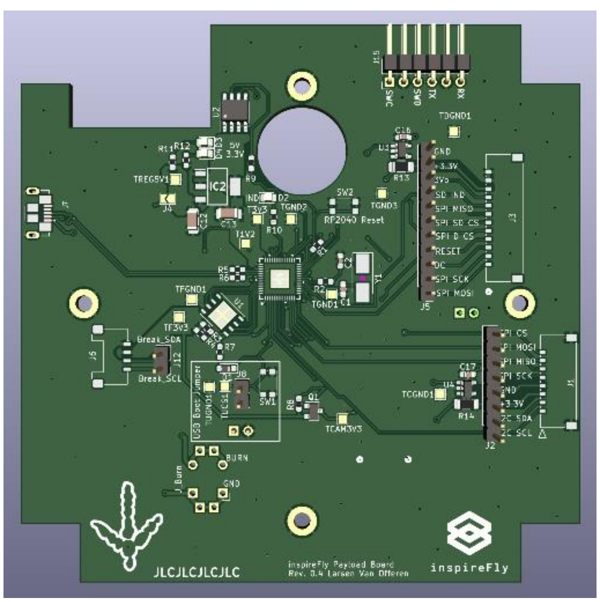

Figure 2: Payload PCB Design Revision

These cutouts were an ideal solution because it meant that a larger camera could be fit on the CubeSat than possible otherwise. By designing an interior housing for the camera, the excess internal space could be used to its maximum potential. It also significantly simplifies wiring for the camera and display screen.

Mirror & Optics Testing

To find the best camera option to suit the needs of the ContentCube, a trade study was conducted on different ArduCam cameras that considered various parameters. These parameters include focal distance, autofocus capabilities, power requirements, size, cost, and flight heritage. Ultimately, the ArduCam 3MP Mega and the OV2640 camera were deemed the team’s best options thanks to their flight heritage and being M12 lens friendly. By utilizing M12 camera lenses, we were able to adjust the focal point and field of view of the camera.

Tests were conducted in parallel for both cameras. Camera testing was performed at different boom lengths and fields of view. It was found that a 160° lens at a 2.0 in boom length was optimal for image quality. This condition was true for both the 3MP and OV2640 cameras. With successful tests, a comparison of both sides’ results can be found in Figure 3.

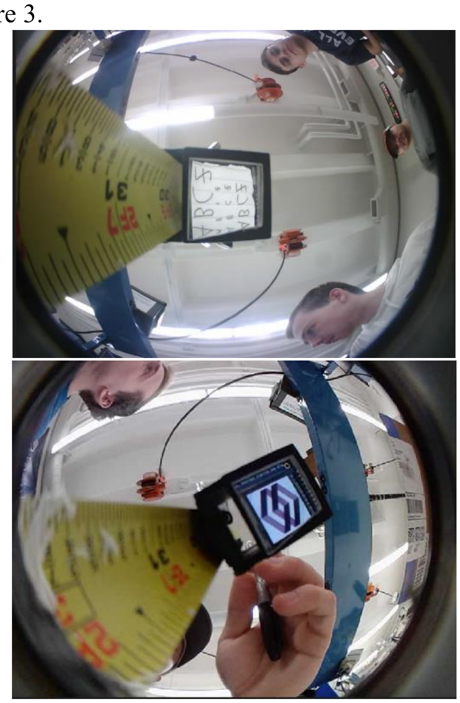

Figure 3: OV2640 Lens Tests (Top) 3MP Mega Tests (Bottom)

At the time the display screen was inoperable for the OV2640 photo and instead varying word sizes were used to test the quality. With both sides of equal quality, more realistic tests were undertaken. Specifically, the team looked at how the quality holds up when in a dark room or when a flashlight is pointed at it. These tests were conducted to simulate the dark and glare-inducing environment of space. Shown in Figure 4 is a photo comparison in a dark setting with the flashlight pointed at both cameras.

Figure 4: Dark Mode with Sun Tests for OV2640 (Top) and 3MP Mega (Bottom)

One can see that the glare produced in the OV2640 is overwhelming the photosensor and therefore makes it unusable for InspireFly's mission objective of taking a picture of the display screen. The 3MP camera image has some glare on the screen but this was only achievable from a very specific, small range of angles. Based on these images, the Mission Operations Sub-Team decided it was best to select the 3MP Arducam Mega Camera for the ContentCube mission.

An IR filter is built within the M12 lenses to prevent damage to the sun sensor. Tinting mechanisms such as a neutral density filter or film were also investigated for both the OV2640 and the 3MP to prevent this glare. Tinting solves the problem for that situation but unfortunately induces more complexity due to outgassing and mounting issues on the payload board. It was also later found that the software integration requirements for the OV2640 are much more complex than that of the 3MP Mega. After much testing, it was determined that the 3MP Mega with an M12 lens of 160° at a 2.0 in boom length configuration is optimal for image quality. Outside tests were also conducted to stress test the camera by pointing it directly at the sun. Due to the IR filter within the lens, it survived 10 minutes with no noticeable defects. Thus, it can be concluded that if the camera were to take a picture directly of the sun, the mission would not be compromised.

Boom Design

During the initial stages of the project, several boom designs were evaluated to meet the mission requirements. The wrap-around tape spring design seen in Figure 5 featured a tape spring that was cut from a tape measure and wrapped around the satellite. The tape spring would be mounted onto a bracket and held in place by multiple burn wires. This design offers simplicity, with few moving parts, ease of construction, and cost-effectiveness, while also enabling compact stowage. However, potential points of failure include limited security, susceptibility to early deployment from launch vibrations, alteration of system moment of inertia, potential torque induction leading to satellite tumbling, and the risk of burn wire failure. All these risks necessitate thorough testing.

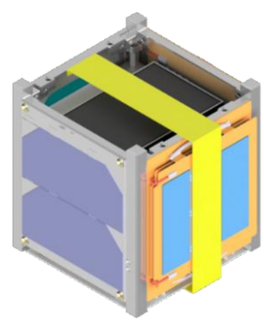

Figure 5: Tape Measure Boom Arm Design

The other notable design considered was a telescoping boom, seen in Figure 6. To extend the boom to length, compression springs between each telescoping piece provided the force needed. A wire would be used to keep the segments together and would be cut using a thermal knife. In addition, the segments would feature roller springs to help with movement and lock joints in after extension. The design offers advantages such as gentler extension force, minimized variation in telescoping direction with guided and locked parts, and straightforward camera attachment. However, potential points of failure include a larger number of high precision components and height constraints requiring a dedicated horizontal plate within the CubeSat. This design would require careful design, manufacturing, and testing.

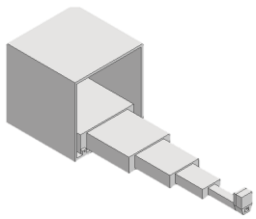

Figure 6: Telescoping Boom Arm Design

After testing with the camera, the team realized the boom would not have to be the original estimate of 30 cm, but closer to 5 cm. Considering this and the benefits and points of failure of the multiple designs, the team concluded that the wrap-around tape spring design should be used for its overall simplicity. Due to the boom being much shorter than anticipated, the boom would no longer have to wrap around the entire CubeSat, but just a portion of the payload board. This change made it significantly more space efficient than the other designs. The smaller boom would also only need a singular burn wire to secure it, minimizing the points of failure for this design.

For the boom configuration, the original options included having the camera at the end of the boom and an OLED screen on the payload board or having an OLED screen at the boom's end and a camera on the payload board. After consideration, both options were eventually scrapped due to the complexities of having wires extend with the boom. Instead, a third option was explored. This alternative design involved integrating both the camera and OLED screen onto the payload board, eliminating the need for extensive wiring along the boom. For the camera to capture an image of the working screen, a mirror would be mounted onto the boom, to allow the camera to capture the reflection of the screen. This approach simplified the electrical implementation of the system, as we no longer had to worry about complex wiring systems. However, it does have a downside in introducing a mirror which could break due to vibrations. To adapt the payload board for this design three cutouts had to be made, one for the camera, to ensure the camera lens is flushed with the payload board face. The last two are for the boom itself, one for where the boom exits the payload board, and another to house the mirror and mirror mount in the satellite's retracted configuration. The final design can be seen in Figure 7.

Figure 7: Final Boom Arm Design, Deployed (Top) and Stowed (Bottom)

MISSION DESIGN

Thermal/Power Analysis

A thermal and power analysis estimate was performed for CubeSat using the MATLAB toolbox "CubeSat Thermal Power Toolbox".[6] Within the toolbox, one can specify the orbital parameters of the CubeSat. Since ContentCube will be deployed from the ISS, the following parameters were used for an ISS orbit on November 8, 2023:

- Semi-major axis: 6711 km
- Eccentricity: 0.000131
- Inclination: 51.6°
- Right Ascension of Ascending Node: 333.4°
- Argument of Periapsis: 90.8°
- True Anomaly: 42.05°

The toolbox also required the characteristics of the satellite. The mass of the satellite is estimated to be 1.33kg and there are six solar panels located on the positive and negative X Y faces that have an individual area of $9.66 * 10^{-4}$ m^2 and bring in a max power (Pmax) of 179.6 mW. This gives a packing factor (ratio of solar panel area to full face of cube) of

58% and a cell efficiency of 19% for each face. Where cell efficiency can be found from the following equation:

$$\text{Cell Efficiency} = \frac{\text{Pmax}}{\text{Area}*1000} * 100 \qquad (1)$$

The thermal resistances for the faces were also all treated as aluminum coated in black with an average solar flux having a value of 1373 W/m^2 and albedo of 0.3. Lastly, power consumption characteristics are also required. The CubeSat has 4 power modes that it will cycle through as shown in Table 1 below:

Table 1: ContentCube Power Consumption Modes

Mode	Voltage (V)	Amperage (A)	Wattage (W)
First Orbit	7.20	0.159	1.14
Normal Operations	7.20	0.187	1.35
Short Hibernate	6.80	0.131	0.891
Long Hibernate	6.60	0.130	0.858

Each mode is assumed to have constant power consumption for the worst-case scenario and each simulation is run for a duration of 10 hours or approximately 6.5 orbits around earth. The following results were then plotted on the graphs in Figures 8 and 9 below:

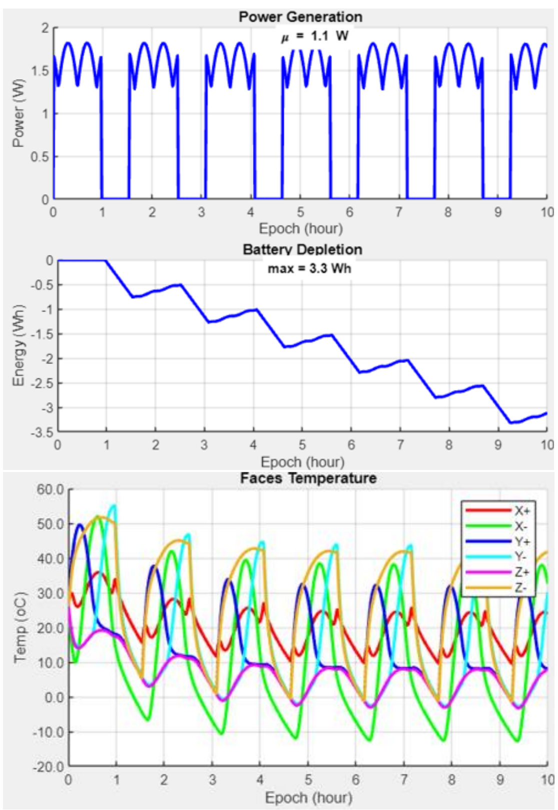

Figure 8: Normal Operations Mode Power Generation, Battery Depletion, and Faces Temperature

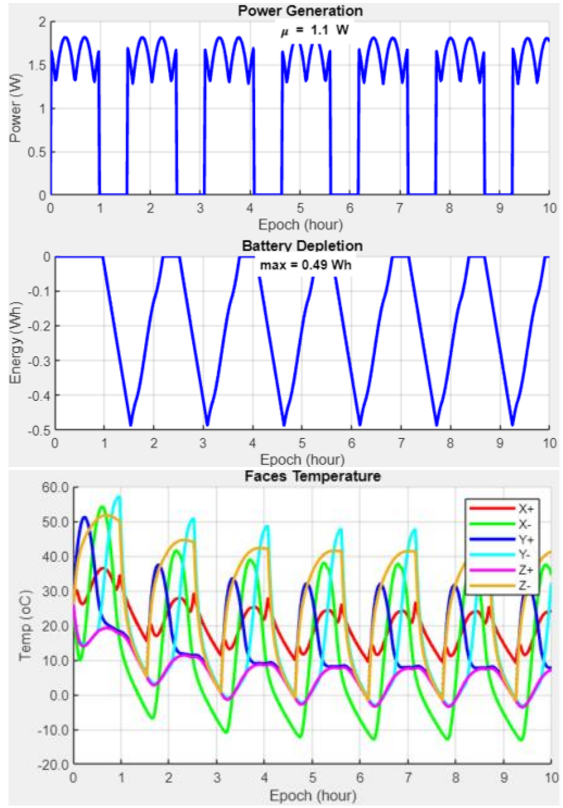

Figure 9: Long Hibernation Mode Power Generation, Battery Depletion, and Faces Temperature

Similarities were found between the first orbit and normal operation modes, and the short and long hibernation modes. The results of normal operations mode are seen in Figure 8, and the results of long hibernation mode are seen in Figure 9. The results from the first orbit mode and short hibernate mode were excluded for conciseness. Two main takeaways were found from these simulations.

The first important finding is that the batteries lose charge during first orbit and normal operation modes. However, the short and long hibernation estimates show that the batteries will regain charge. This confirms that these modes are doing their respective jobs, and that the battery should have around a 1 W-h capacity to orbit the Earth one time.

The second takeaway is that the face temperature reaches a minimum of -10 °C. This is similar to the initial estimates from past years and gives an estimate of what the minimum temperature the payload board should experience. It should be noted that this is a worst-case scenario, and that the internal temperature of the CubeSat will be higher. Additionally, this calculation matches the measured temperature data from the SwissCube mission.[7]

Image Size Analysis

To get an estimate of the downlink time for a photo taken from the CubeSat, the image file size must be estimated beforehand to properly account for packetization. Image size depends on three factors: file type, resolution, and color noise. The Arducam 3MP Mega camera outputs a .jpg image file with options for a variety of resolutions that can be configured through software. Color noise is dependent on resolution and how detailed the background is overall. A photo of a solid black background takes less bytes to store than a photo of Earth with green, brown, blue, black, and white colors.

Since space is not easily accessible for testing, an experiment was carried out by setting up the camera to take pictures of different resolutions on a TV displaying different images. One of the pictures can be seen below in Figure 10.

Figure 10: Picture of Earths Background at Resolution of 640x480

Six photos were taken at resolutions of (1) 320x240, (2) 640x480, (3) 1280x720, (4) 1600x1200, and (5) 1920x1080 respectively. Figure 11 below shows the average file size at each resolution, and the transmission time of each file size. The file size is plotted in blue, and the transmission time is plotted in orange.

Figure 11: Earth Background Photo Sizes at Different Resolutions

The x axis follows the same order the resolutions were mentioned in earlier, going from lowest to highest. As expected, the higher the resolution, the higher the file size. Assuming the maximum file size of 140KB, and a transmission rate of 9600 bps, transmitting an image will take 117 seconds assuming constant transmission.

Mission Plan

ContentCube will launch to the ISS, where it will deploy from the NanoRacks CubeSat Deployer. Per Nanoracks Interface Definition Document, ContentCube must wait 30 minutes before it can begin turning on and deploying its antenna and boom arm.[8] To ensure compliance, 30 minutes after being deployed, the satellite will activate, and 45 minutes after deployment, the satellite will activate the burn wires for its antenna and boom arm. Once fully deployed, the satellite will enter its main state machine. The state machine changes states based on the voltage level of the batteries. The state machines default case is 'normal power mode.' ContentCube is in 'normal power mode' when the battery voltage is greater than 6.9 volts. In this mode, the satellite polls health data and beacons every 30 seconds. The beacon message contains the voltage level and if the payload has taken a picture. If the payload has not taken a picture, the main bus will command the payload to enter picture-taking mode. In this mode, the payload board polls a light sensor to find an optimum time to take a picture. If the light sensor is at a relative minimum, a picture will be taken as the camera on the payload face is not pointed directly at the sun. If the VTGS receives the beacon, it will respond with a request for the full state of health (SOH) report. This report contains all the health data of the satellite, including system voltage, battery voltage, current draw, charge current, temperature data, and if it has taken a picture. Once the satellite hears the ground station request, it will respond with the SOH. If the ground station receives the SOH and confirms the satellite has taken a picture, it will request a picture packet at index n, where n is an integer determined by the ground station. By requesting the picture using indexed packets, only the ground station is required to keep track of which packets have been successfully transmitted and received. Only having the ground station responsible for the index reduces the amount of data that needs to be coordinated between the satellite and the ground station, increasing the overall data transmission rate. Additionally, if the satellite leaves the range of the ground station while transmitting the picture packets, the ground station will save the current index allowing for the image transfer to resume once communications are reestablished.

The second operation mode of the satellite is low power mode. This mode occurs when the system voltage is between 6.6V and 6.9V. While in low power mode, the satellite beacons every 120 seconds. This will allow the satellite to recover back to normal power mode, assuming it can reach that state again. If a picture needs to be taken, the main bus will still tell the payload to go into picture mode. Likewise, if the ground station hears that the satellite has a picture to transmit while in low power mode, it will request the picture be transmitted.

The final mode of operation is hibernation. This mode occurs when the system voltage is below 6.6V. In this mode, the satellite beacons every 6 minutes and tells the payload board to cease all functions. By shutting everything down except for the onboard computer and battery heaters, the satellite will attempt to restore power to normal operations mode. If the ground station hears that the satellite is in hibernation mode, it will not request a picture from the satellite.

Finally, if the ground station has successfully received an image from the satellite, it will attempt to transmit a new image for the satellite to take a picture of. Similarly to the satellite transmitting an image down only in normal or low power mode, the ground station will only transmit an image up when the satellite is in normal or low power mode. Before the ground station begins transmitting an image, it will first tell the satellite to delete the current saved image. The ground station oversees image deletion to ensure that ContentCube does not prematurely delete an image. In addition, it will prevent memory issues within the satellite, as there will always only be one image for the satellite to handle at a time.

COMMUNICATIONS SYSTEM

Due to inspireFly utilizing the PROVES Kit, and the Virginia Tech Ground station already being established, many aspects of the communications system were predetermined for this mission.[4] However, considerable design was put into the packet definitions and communication plan to ensure the highest chance of mission success.

PROVES Kit Radio Module

The radio module the PROVES Kit utilizes is the HopeRF RFM98W. This module is being used to transmit packetized information at 9600 bits per second while utilizing Gaussian minimum frequency shift keying to modulate the data. The downside of using this radio is that there is a 60-byte limit on the packet size. The antenna being used on the satellite is the Endurosat UHF III antenna. This antenna was chosen as it has an omnidirectional pattern, over 0dBi, and flight heritage. This will increase the chance of a successful link being established and held, even while tumbling.

Virginia Tech Ground Station

The Virginia Tech Ground Station features a Yagi-Uda antenna with a gain of 17.9dB, which makes establishing a link between Content Cube and the ground station trivial. The link budget calculation can be seen in Table 2. The ground station required that we transmit AX.25 packets wrapped in the KISS protocol, meaning we could not use the LoRa capabilities of our radio module. This was deemed as a necessary tradeoff to make, as constructing our own ground station required both funding and manpower the team does not have.

The actual integration into the Virginia Tech Ground Station is taking place over Summer 2024. This work will involve writing code to allow for the automated tracking of ContentCube and writing code for the ground station to automatically communicate with ContentCube. The work inspireFly will do to make the ground station operational for ContentCube will pave the way for future cube sat missions to easily integrate into the ground station. Future plans include adding LoRa support and support for other radio bands.

Table 2: Link Budget

Parameter	Value
Downlink Frequency	435 MHz
Target SNR	9.6 dB
Implementation Loss	1.0 dB
Required Eb/No	10.6 dB
Transmit Power	20.0 dBm
Transmit Antenna Gain	2.2 dB
Transmit Losses	-1.0 dB
Transmit Pointing Losses	-2.0 dB
Transmit EIRP	19.2 dBm
Link Distance	450.0 km
Downlink Path Loss	-138.3 dB
Polarization Losses	-3.0 dB
Receive Antenna Gain	17.9 dB
Receive Pointing Losses	-2.0 dB
Received Power	-106.3 dBm
Comp Noise Temp	200.0 K
Antenna Noise Temp	100.0 K
System Noise Temp	300.0 K
System Noise Figure	3.1 dB
Noise Bandwidth	9600.0 Hz
Noise Floor	-131.1 dBm
Eb/No	24.8 dB
Link Margin	14.2 dB

Packet Definition

The packet requirements of AX.25 and KISS add 22 bytes of overhead data to each packet of 60 bytes, giving a packet efficiency of 63.33%. To utilize the remaining 38 bytes as efficiently as possible, it was decided that the satellite would not transmit unnecessary overhead data. For example, the provided code from Bronco Space has the satellite transmitting strings of text to help a human read the transmitted data. We are removing all these instances, and instead only transmitting the raw data. This decision is necessary due to the large amount of data we are transmitting. Factoring in the required health data and possible retransmissions, every second of contact time with the ground station needs to be used efficiently.

CONCLUSION

ContentCube will serve as a useful test for furthering space technology by testing the feasibility of display screens exposed to space. The team is on track to begin testing the final design in Fall 2024 and perform a successful handoff to our launch provider by the end of 2024. This handoff will wrap up multiple years' worth of work and allow inspireFly to move on to future projects. Additionally, the successful operation of ContentCube will serve as proof that Bronco Space's mission of making an easily modifiable 1U satellite bus for rapid development with the PROVES Kit is a success. Through the lessons learned, and documentation created, it is the hope that future projects will have faster turnaround times.

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