The Mission for Education and Multimedia Engagement: Breaking the Barriers to Satellite Education

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***Abstract*—The Mission for Education and Multimedia Engagement Satellite (MEMESat-1) is a 2U satellite built by a team of twenty-two multidisciplinary undergraduate students at the University of Georgia Small Satellite Research Laboratory. The mission client is Let's Go To Space Inc., a non-profit organization dedicated to K-12 outreach; this mission is funded by donations to Let's Go To Space Inc. and a grant titled the Mission for Education and Multimedia Engagement from the Georgia Space Grant Consortium.**

MEMESat-1 helps solve the barrier-to-entry problem in aerospace development by giving undergraduate students first-hand experience with developing a small spacecraft from the ground up, expanding K-12 accessibility to aerospace education, and providing a public platform for satellite interaction. It serves to educate college students on the intricacies of satellite development. Each subsystem team is led and fully staffed by undergraduate students who are responsible for every stage of stack development, from conception to launch. Development, assembly, testing, and validation of the avionics stack are done almost entirely in-house, cultivating a deeper understanding of otherwise black-box subsystems. Let's Go To Space will host an online portal for K-12 students to interact with and learn about MEMESat-1 while providing related educational information about space, physics, and radios. MEMESat-1 uses the open-source Little Free Radio in collaboration with the University of Buffalo Nanosatellite Laboratory. The Little Free Radio will transmit and receive images and audio over amateur radio bands, serve as a digital transceiver for the amateur radio community, and allow amateur radio users to interact with the satellite.

NOMENCLATURE

$2S-2P$	2 in series, 2 in parallel
BBS	Bulletin Board System
$BoBa$	Board of Batteries
CAD	Computer-Aided Design
$CM4$	Compute Module 4
$COSMO$	Center for Orbital Satellite Mission Operations
$COTS$	Consumer Off-The-Shelf
$EIRP$	Equivalent Isotropically Radiated Power
EPS	Electrical Power System
F'	F Prime
FSK	Frequency Shift-Keying
$GMSK$	Gaussian Modulation Shift-Keying
$GSGC$	Georgia Space Grant Consortium
I/O	Input/Output
LFR	Little Free Radio
MCU	Microcontroller Unit
$MPPT$	Maximum Power Point Tracking
OBC	On-Board Computer
$PoBoI$	Power Board/Interface
RAM	Random Access Memory
$RFIC$	Radio Frequency Integrated Circuit
SDR	Software Defined Radio
SOC	System on a Chip
$SSRL$	Small Satellite Research Lab
TNC	Terminal Node Controller
$TVAC$	Thermal Vacuum Chamber
$UBNL$	The University at Buffalo Nanosatellite Laboratory
UGA	The University of Georgia
UHF	Ultra-High Frequency
VHF	Very-High Frequency

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1. INTRODUCTION

MEMESat-1 is a low-cost, 2U nanosatellite that will communicate memes via amateur radio from Low Earth Orbit.

MEMESat-1 directly supports NASA's Strategic Goals 2.0 and 3.0 for STEM engagement by working to "create and deploy authentic learning experiences and research opportunities for students to bolster their STEM studies and stimulate further interest and achievement" [1]. The project achieves this by providing college students the opportunity to use skills they have learned in classes in space-specific applications, better preparing them for a career in the aerospace industry than through class work alone. The University of Georgia does not offer an Aerospace Engineering major, and the UGA Small Satellite Research Laboratory (SSRL) serves as a pathway for students to prepare for and pursue careers in the space industry. MEMESat-1 is jointly funded by the non-profit organization Let's Go To Space and the Georgia Space Grant Consortium under a grant entitled "The Mission for Education and Multimedia Engagement", in the higher education category. MEMESat-1 is planned to launch in the winter of 2023 and will be developed with a budget of $25,000.

The Small Satellite Research Laboratory at the University of Georgia is cooperating with the University at Buffalo Nanosatellite Laboratory to develop their Little Free Radio, which will serve as MEMESat-1's communication system. MEMESat-1 will transmit its payload over packet radio and send telemetry data over Ultra-High Frequency radio. Commands to MEMESat-1 will be encrypted and sent only from the UGA ground station, the Center for Orbital Satellite Mission Operations.

2. Mission Operations

The client requires three mission objectives: to serve as a digital transceiver for the amateur radio community, to transmit memes on orbit and accept meme uplinks, and to train students in STEM-related fields such as manufacturing, radio communication, and space-tolerant system design. In addition to client requirements, MEMESat-1 largely follows guidelines and standards outlined in [2][3][4]. MEMESat-1 will have two payloads: the primary payload will be JPEG-formatted images, and bulletin board system messages as the secondary. To satisfy minimum mission success criteria, MEMESat-1 will have full capability to uplink and downlink the primary payload and engage in BBS operations for at least 6 hours each orbit. The mission's operations team expects to manage the transmission and downlink of at least one meme per ground station pass, of which MEMESat-1 will have 3 to 4 in 24 hours (internal calculations; not shown here). To satisfy the objectives of amateur radio interaction, MEMESat-1 will host a bulletin board system. The BBS can be pinged by HAM users and will queue the received radio message for later transmission. As part of the mission's outreach initiative, any user with internet access can access the BBS through a GUI that will be hosted on letsgo2space.com. All such interactions will go through an intermediate radio operator, so the end user will not be required to have a radio license. The BBS will be the public interface for meme submissions and will provide users with MEMESat-1's approximate orbital position, subsystem health reports, and the current meme(s) onboard.

Modes

MEMESat-1 will have three operational modes: Cruise Mode, Anomalous Safe Mode, and Critical Power Safe Mode. Cruise Mode operations will entail image uplink/downlink, BBS operations, and health beaconing every 60 seconds. If any unexpected system behavior is detected, MEMESat-1 will transition into Anomalous Safe Mode, ceasing payload operations and only transmitting system health telemetry. Critical Power Safe Mode will serve as a brown-out to allow the batteries to charge back up to a safe level. During Critical Power Safe Mode, MEMESat-1 will perform no observable operations. Upon transition into this mode, the OBC will be shut down to reduce the power draw of the satellite. The EPS microcontroller will monitor system health and control the active components, gathering data until it can be downlinked in a log during the next COSMO pass. The MCU will monitor the battery voltage to determine when to transition back into cruise mode. During the transition to Cruise mode, the MCU will power on the Raspberry Pi and wait for the handshake that signifies successful boot and flight software initialization. If any errors occur in Critical Power Safe mode, the EPS MCU will transition to Anomalous safe mode and repeatedly send packets indicating an error state; it will power cycle the satellite in an attempt to resolve the error.

3. Communication System

LFR

MEMESat-1 uses the Little Free Radio, an open-source command, telemetry, and data radio developed by the University of Buffalo Nanosatellite Laboratory [5]. LFR utilizes the Texas Instruments MSP430FR5994, a low-power integrated processor that handles interfacing with both the Radio Frequency Integrated Circuit and MEMESat-1's OBC. MEMESat-1's LFR implementation uses the Silicon Labs Si4468 RFIC, a transceiver IC that can operate across a wide range of UHF and VHF frequencies. MEMESat-1 is currently utilizing the half-duplex iteration of LFR and can uplink/downlink within UHF (435-438 MHz) or both UHF and VHF (144- 149.9 MHz) bands. The primary difference between downlinking on UHF versus VHF is that UHF provides the potential for a higher data rate, but VHF allows for less path loss[6]. Because UHF has a higher frequency range than VHF and a larger bandwidth, more data may be transmitted over the same time interval [7]. The UHF band is also less crowded than the VHF band, but operating in a higher frequency range necessitates a higher signal strength, increasing power consumption [7]. UHF generally produces less signal noise but is more greatly affected by the Doppler shift [8]. This adverse effect should not pose an issue as SSRL's ground station, the Center for Orbital Satellite Mission Operations, takes the Doppler shift into account in real time. Moreover, the complications of implementing dual-band operations on a half-duplex radio outweigh the benefit of downlinking VHF. The choice to pursue UHF uplink and downlink is supported by link budgets calculated for UHF uplink/ downlink and UHF/VHF uplink/downlink schemes, concluding that both options result in generous link margins. MEMESat-1 will transmit and receive using 437.45MHz.

The uplink margin is found by subtracting the downlink path loss from the Spacecraft EIRP.

$$U = Spacecraft_{EIRP} - Downlink_{PathLoss} \tag{1}$$

The downlink margin is found by subtracting the SNR per bit from the Signal to Noise power ratio.

$$D = \frac{P_s}{P_n} - \frac{E_b}{N_o} \tag{2}$$

From the previous equations, MEMESat-1's uplink and downlink margins were calculated.

	SNR (dB)	SNR per bit (dB)	Margin (dB)
Uplink	35.2	9.4	25.8
Downlink	50.5	9.4	41.1

Table 1. **Uplink and Downlink Margin Table**

The communication system can withstand 25.8 dB of signal attenuation during uplink and 41.1 dB during downlink before reception and transmission are compromised.

Modulation Scheme

MEMESat-1 had two options for packet modulation: GMSK or FSK. Given the same bandwidth, GMSK can transmit more data than FSK because the symbol rate can increase to satisfy the Nyquist inequality. The Nyquist inequality represents the upper bound for transmission data rate, C, as a function of bandwidth, B, and number of signal levels, M [9].

$$C \geq 2B \log_2 M \tag{3}$$

Using GMSK will reduce the average SNR in favor of a smaller bandwidth and cleaner signal [10]. To use GMSK, we will set the modulation type to FSK and the modulation index to 0.5, calculated using the ratio of frequency deviation over modulating frequency.

The standard packet data rate for VHF and UHF radio is 1200 baud, though TNCs can generate higher data rates, making 9600 baud practical for most amateur radio users [11]. With an approximate downlink/uplink time of 150 seconds, MEMESat-1 can transmit 0.1875MB of data per uplink/downlink. While further increasing the baud rate is possible with LFR, this will make it harder to use a hardware TNC and makes the signal more susceptible to noise, potentially rendering it unusable by low-end SDRs. However, because end-users will have a limited time to communicate with the satellite during a pass, a higher data rate is favorable for effective communication.

Bulletin Board System

MEMESat-1's secondary payload, the bulletin board system, was a popular type of interactive server application in the 1980s that allowed users to share and exchange messages over a network [12]. The BBS fulfills MEMESat-1's mission objective of serving as a transceiver for the amateur radio community and allows for an additional layer of student interaction, specifically for those not already involved in the amateur radio community. Initially, MEMESat-1 was intended to act as a repeater, but due to the lightweight nature of LFR, it is not capable of full repeating capability. The team decided that maintaining the educational partnership with UBNL was more important to the mission, opting to implement a Bulletin Board System rather than a repeater. The BBS gives the MEMESat-1 Mission Operations team more control over the communications schedule as opposed to a repeater and allows for LFR to remain our sole radio.

BBS messages may be directly uplinked to the satellite or through a web interface hosted on our lab server. This extra layer of interaction is supplemental to the nominal operations of the BBS, allowing it to function irrespective of the status of the web interface. Messages directly uplinked to the satellite will be cross-checked with a dictionary to moderate sensitive language. Messages sent through the server will undergo a more rigorous moderation procedure, such as collaborative moderating, so all messages displayed on the GUI will be appropriate for all ages to view [13].

The SDR modem needed for transmitting and receiving packets to/from MEMESat-1 will be open-source. This modem will be created in GNU Radio and will enable users to send, decode, and read packets to/from MEMESat-1. MEMESat-1 will utilize the SatNOGS network, an open-source, global system of satellite ground stations fueled by volunteers. Volunteers can use MEMESat-1's API to stream messages from our web server for uplinking to the satellite using their equipment. Anyone can access this packet modem, and even the most modest station can independently engage in the BBS. Web-submitted messages will send API requests to a SatNOGS ground station, which will then send a request for the satellite to downlink its BBS logs for periodic updating of the online database. Periodically, the satellite will also receive BBS uplinks of messages submitted through the web interface for transmission under the satellite's call sign.

Antenna

MEMESat-1's antenna development is led by Jordanne Brisby, a junior studying atmospheric sciences. Brisby was initially worried they would not be able to contribute to the mission in the same capacity as their engineering and computer science peers; however, they "quickly found [their] place on the team." MEMESat-1, being an amateur radio satellite, encouraged them to "get [their] amateur radio license, a subject in which [they] previously knew nothing about." Now, months later, it is one of their "greatest passions and hobbies, allowing [them] to find [their] special place on the MEME team." Through research, Brisby and the communications team narrowed in-house solutions to UHF monopole, dipole, separated turnstile, or crossed turnstile antennas. With MEMESat-1's generous link margins of approximately 25dB, the team has determined that a linearly polarized monopole antenna will be sufficient for our mission, meeting required specifications while minimizing antenna mounting and deployment complications. While the current model utilizes a strip of household measuring tape, many Consumer Off-The-Shelf antennas utilize proprietary alloys. The team plans to investigate COTS antennas, such as the ISISpace CubeSat Antenna System or the EnduroSat UHF Antenna Module, to identify alternative materials for space-flight antennas. Through their research, Brisby "get[s] to do hands-on work with the antenna system and gleefully unleash [their] creative freedom, all with the knowledge that one day my creation will serve a purpose; one that gets the opportunity to make a difference in the educational, amateur radio, and STEM communities."

The team has created the first iteration of the antenna for testing, which will be mounted to the aluminum frame to simulate an infinite ground plane, which can not be measured accurately due to the finite dimensions of measurement systems [14]. Therefore, the model can still be tested to verify antenna behavior, but the infinite ground plane must be tested through MatLab simulations and verified by implementing the antenna design.

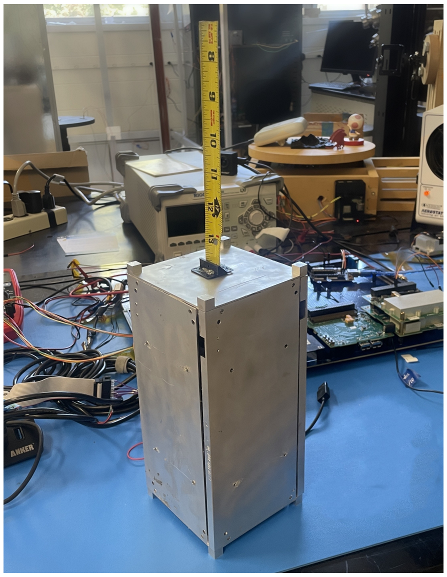

Figure 1. **2U aluminum body with mounted antenna**

4. ATTITUDE CONTROL

MEMESat-1 will use a Passive Magnetic Attitude Control System to stabilize the satellite without drawing additional power. Because MEMESat-1 does not have directionally sensitive instruments and the link budget closes even at large off-Nadir angles, passive stabilization is sufficient to achieve mission success. Pointing requirements are driven by the antenna, whose radiation pattern profile permits closing our link budget more than 25% of the time with passive stabilization. MEMESat-1 will use permanent magnets, hysteresis rods, and nutation dampers to stabilize the satellite along two axes. This system will ensure that the satellite is adequately oriented along two axes to close the link. The validation of this system will mostly rely on simulated models, which will help determine the control hardware parameters, such as the dipole moment of the permanent magnet and saturation and remanence of the hysteresis rods. Permanent magnets, hysteresis rods, and nutation dampers are simulated to understand requisite characteristics. For bar magnets, physical testing necessitates using a Helmholtz cage and a magnetometer to measure their magnetic moments. For hysteresis rods, a sense coil and integrator will be used inside the Helmholtz cage to gather the average interior magnetic flux density[15].

5. PAYLOAD AND COMMAND HANDLING

The MEMESat-1 command and data handling module will use the Raspberry Pi Compute Module 4. The Compute Module form factor requires a carrier board to access the board peripherals and is designed for use in highly embedded applications, forgoing the ease-of-use associated with the Raspberry Pi to give the user access to more of the signals available from the system on a chip. MEMESat-1 uses a custom Linux distribution that only contains the dependencies needed to run the flight software. The total size of the operating system will be less than 2 Gigabytes and will be stored on all SD cards for redundancy. Additional mission data, including the primary payload, secondary payload, health beacon data, and additional operating system copies, will also be stored on multiple SD cards. Each image in the payload will be 320 x 240 JPEG with an 8-bit color depth. The image size is limited to 0.025 MB, where any file greater than this will be compressed using a convolutional auto-encoder. This limitation was derived from the uplink and downlink speed of LFR: only 0.1875 MB may be sent per uplink and downlink within a link time of 150 seconds, which is an average pass time calculated from orbital simulations at 400km, 408km, and 475km.

MEMESat-1's flight software suite is based on NASA Jet Propulsion Laboratory's F Prime, an open-source Flight Software primarily written in C++. F' utilizes Publisher-Subscriber-based architecture, which allows users to create, and unit test for discrete applications. The mission-specific flight software architecture is built by connecting the individual components through ports. The ports facilitate communication between the processes using the messaging backend implemented in F Prime. The flight software team is working on the custom components needed to fulfill the MEMESat-1 mission: health monitoring, primary and secondary payload management, and communication. Satellite health information will be gathered from the EPS subsystem through a UART connection with the EPS microcontroller. The health data will be stored in the flight software telemetry database built into F'. The primary payload is managed with the file management component built by Aiden Hammond. Hammond is a Sophomore double major in astrophysics and computer science; he attributes "a lot of [his] personal growth to the mission and all of the like-minded, knowledgeable people that [he] has been working with" as a member of MEMESat-1. He is learning how to design systems for critical, highly embedded applications. Hammond says that this is a "completely new way of structuring code because there is little room for error," this constraint has pushed him to "work more thoroughly and with greater intent," fostering a better understanding of the computers and how the decisions he makes affect the reliability of the system. Hammond will be helping design the tools needed to validate the flight software; F' includes a framework for designing system tests and simulating mission scenarios. With these tools, the flight software team will be able to perform a day-in-the-life test with the full avionics stack to validate the entire system before integration.

Memory redundancy is an essential aspect of this mission. The OBC will use off-the-shelf components which do not undergo testing to certify their operation in Space. MEMESat-1 will have multiple SD cards that store copies of the operating system and payload in separate partitions. Payload data will not be mirrored to the other partitions. The master partition table will be mirrored on the backup SD cards at launch. The backup SD cards will not be updated during flight to minimize the read and write operations. On boot, the operating system will be completely loaded into the Raspberry Pi's RAM, slowing the degradation of the SD flash memory as the operating system performs background tasks. Payload data will have to be written to the active payload partition on the SD card due to the limited amount of available RAM.

6. ELECTRICAL POWER SYSTEM

The EPS for MEMESat-1 is designed in-house and has the following constituents: the maximum power point tracking board, the voltage rail board, the battery board, and the solar panel boards. Electrical team lead and senior Electrical Engineering student, Matthew Olson, oversees the development of the EPS. His experience in the lab has "allowed [him] to grow as an Electrical Engineer, leader, and team member, teaching [him] things that my classes have not, and helping me get my foot in the door of industry." Additionally, Olson's experience in the lab enabled him to intern at NASA Ames Research Center on the PACE (Payload Accelerator for CubeSat Endeavors) Project. The PACE project, like MEMESat-1, strives to create the satellite stack in-house, allowing Olson to utilize the skills he learned at the lab in industry and bring new knowledge to the lab through his experience in seeing "professional engineers work and create robust designs." When asked about his MEMESat-1 experience, Olson states that "MEMESat-1 has given me the opportunity to create subsystems from scratch, which is a process that [his] time on other missions has not given [him]."

PoBoI

Cate Davis, a senior electrical engineering student, and MEMESat-1's senior PCB designer, co-designed MEMESat-1's custom Power Board/Interface, shown in 2. Davis has worked on MEMESat-1 since its conception and has since developed her PCB design and assembly skills, learning about "signal integrity, simple power electronics, circuitry simulations in LTSpice, time management, and iterative engineering design process." POBOI consists of the MPPT circuit, power conditioning and monitoring circuits, and three voltage rails: 3.3V, 5V, and VBatt (6.8V-8.4V). The MPPT serves as the battery charge controller by adjusting the output voltage and current of the solar panels. Maximum power point tracking and charging functionalities are controlled via an IC chip with external power converting and feedback circuitry. Boards are iteratively tested through functional unit tests, subsystem tests, and full system testing. POBOI uses buck converters, current monitors, and the STM32 microcontroller for power distribution and monitoring. Voltage rails are bucked with a high-impedance voltage divider to protect the inputs of the MCU from high-voltage damage. The current monitor outputs voltages across a sensing resistor so that the MCU can derive current from the sensed voltage. All analog power monitoring inputs have overcurrent protection in case of failure.

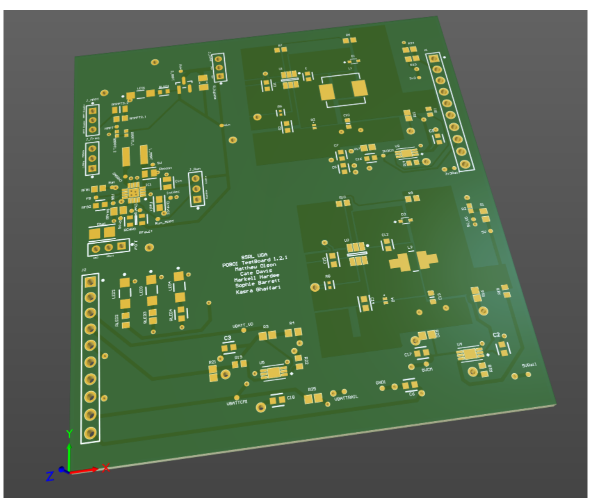

Figure 2. 3D rendering of the Power Board/Interface (POBOI)

BoBa

MEMESat-1 will use a 2S-2P battery to power the satellite during periods of an eclipse. Jonathan Shoemaker, a 2022 graduate, headed the development of MEMESat-1's board of batteries during his time in the lab. Shoemaker now works at Lockheed Martin on aerospace battery systems. He believes that "working on the MEMESat-1 battery system gave [him] the opportunity to explore [his] passion, apply the knowledge directly from [his] courses, and develop skills, confidence, and experience to thrive in the aerospace field." Shoemaker feels that "few other undergraduate opportunities give students the ability to have such a high level of ownership, creative flexibility, and oversight over the entire design, build, and test process," and that his time on MEMESat-1 prepared him in the development of systems for "some of the harshest environments known to man." BoBa features four 18650 Li-Ion cells to maintain the mission objectives of low-cost development. The 3.3V and 5V rails will be derived from the VBatt rail, while the battery voltage rail is voltage directly from the batteries. Each rail is monitored by tracking voltage over time. This monitoring of change in voltage over time for the VBatt rail will give insight into charge cycles and will serve to monitor the health of BoBa. BoBa has two temperature sensors placed directly onto the 18650 Li-Ion cells, which send temperature telemetry to the MCU for monitoring and controlling battery heating.

OBC

The current power budget of MEMESat-1 shows that the system is power-positive even with a 20% contingency. Measurements will be taken for each subsystem to shrink the contingency margin. For the OBC, this looks like stress testing to account for its largest possible power consumption. In preparation for testing a CM4, a stress test was run utilizing a Raspberry Pi 4 to obtain more accurate power draw data from the Compute Module. Power is delivered through the 5V pin, and with a clock signal of 1.5GHz, the current draw was approximately 1A. Using this same stress test, we tested the configuration anticipated for flight, the SOC was underclocked to around 400MHz, and two of the four cores were disabled; core voltage was dropped to 0.9 volts resulting in a current draw of around 0.5A. The power figures from these tests help verify that MEMESat-1's nominal state is power positive.

Solar Array

MEMESat-1 utilizes a 4S-4P solar array design, a system of four solar panels in parallel, each with four cells in series. This project was pioneered by, now alumni, Markell Hardee. Hardee is now an intern at the Aerospace Corporation and a 1st-year M.S Electrical and Computer Engineering student at Georgia Tech. He considers his time on MEMESat-1 crucial to obtaining the opportunities he has today, stating that "being a part of MEMESat-1's mission has allowed [him] to develop [his] soft skills and hard skills to a point where [he] could feel confident in [his] abilities to succeed in [his] aerospace endeavors after obtaining [his] undergraduate degree". Hardee led a small team of undergraduates through solar panel design, testing, and integration procedures. After conducting an extensive tradespace of COTS Solar Cells, Spectrolab's Triple Junction XTE-SF (Standard Fluence) solar cells have been selected as the optimal choice for the MEMESat-1 mission because of their normalized net power, efficiency, coverable surface area, and ease of assembly. After computing power generation across all operational modes, the team concluded that there was not enough usable surface area to support power requirements for the mission. Although these cells outscored its feasible contenders, it was decided that to generate enough power to remain power positive during operations, MEMESat-1 would become a 2U.

7. MECHANICAL

MEMESat-1 is of a 2U form factor with a 1U stack. The 2U frame was created to increase the surface area for solar cells, but the stack size has remained a 1U. The avionics stack is centered in the frame with braces leaving 0.5U of space on either end, as shown in Figure 3. A computer-aided design model was created for use in thermal, modal, and structural simulations. From this CAD, simplified structural models are derived to ensure the satellite does not break under the stress of launch conditions. These models are then subjected to various static and dynamic loading environments: modal, harmonic response, response spectrum, random vibration, and inertial acceleration. These analyses will be compared against overly conservative figures, based on analyses of other SSRL missions. For example, the inertial acceleration analysis is defined by the mass acceleration curve, and responses to this curve will be compared against the 100Hz minimum mode. Once launch provider constraints are obtained, additional analyses will be conducted. Thermal simulations serve to determine the maximum operation time of active components per orbit and to analyze passive thermal components, such as insulating washers or heat straps on active components that generate considerable thermal power.

In later stages of testing, the frame and stack will be subjected to thermal cycling in the Thermal Vacuum Chamber to verify the system's operating temperature. TVAC will be used to cycle through a range of temperatures, ranging from around -20°C to around 60°C, divided into different intervals and performed over an array of different periods. Additionally, the satellite will undergo vibration testing to verify the structural compatibility with the launch environment. MEMESat-1 will have to be transported to a separate facility for vibration testing, options for which include collaboration with other universities and companies or purchasing this service from providers such as Keystone Compliance.

8. FUTURE APPLICATIONS

The MEMESat-1 mission provides both the UGA SSRL and the CubeSat community-at-large with an open-source design for a 2U foundational bus and 1U avionics stack. Being open-source, MEMESat-1 may serve as a foundation for new student teams that want to build a satellite but need help getting started. The component choice promotes interaction with the members of the hobbyist community, their ideas, and their expertise for no additional charge. The Rasberry Pi has ample projects that can be modified for use as the payload for a new MEMESat-1 mission. Its unused GPIO pins can be connected to sensors for data collection, and because it is designed to run Linux, users can easily run custom applications, including other flight software. The compact form factor of the avionics stack allows users to transfer this design to missions requiring different bus form factors with minimal modification.

In MEMESat-1 lies the potential for a GSGC collaboration. Potentially, the development of a grant program based on MEMESat-1's mission platform, which may be utilized across Georgia to expand aerospace education for students of all ages. MEMESat-1 would allow the GSGC to focus on selecting payload proposals for the next Mission for Education and Multimedia Engagement rather than selecting an entity capable of cradle-to-grave mission development. This grant program would encourage colleges across Georgia to get involved in aerospace development. It may also incentivize schools to start satellite programs of their own so that students can get involved in the aerospace field early on.

9. IMPACT

Cultural

Merriam-Webster defines a meme as "an amusing or interesting item (such as a captioned picture or video) or genre of items that is spread widely online, especially through social media [16]" Figure 4. Before the invention of modern social media, there was the Bulletin Board System, which allowed users to log on and connect with each other [12]. MEMESat-1 serves to unite space and radio enthusiasts alike using the system that helped pioneer the social media frontier. MEMESat-1 is breaking the bounds by expanding the reach of memes from the internet to amateur radio and from earth to the thermosphere.

Figure 4. Example Payload Data

MEMESat-1 provides an avenue for all student groups to participate in educational STEM activities. Memes mean different things to different people but serve as a cultural touchstone uniting people of different backgrounds and promoting a spirit of inclusivity. The results of this inclusivity, when combined with a conscious commitment to equity, diversity, and inclusion, is an environment that welcomes student groups who have previously encountered hurdles when engaging in STEM activities. MEMESat-1 helps make space available to everyone because the only required tool for MEMESat-1 engagement is a computer, a device most students can access. Through engaging with MEMESat-1, the practice of interacting with an orbiting satellite is demystified and becomes less daunting for students who may have previously felt intimidated by the learning curve associated with amateur radio or satellite technology.

University students benefit from the same spirit of inclusivity. Although there is occasionally the need for a student with a particular pre-existing technical skill set, student lab members are not required to belong to any particular major to qualify for any lab position; for example, MEMESat-1's communication team was led by a natural resources management major. Teams are composed of students from a variety of backgrounds and interests; the culture of the MEMESat-1 mission encourages students to explore cross-disciplinary concepts and promotes multi-disciplinary collaboration. Students teach each other about different aspects of satellite de-

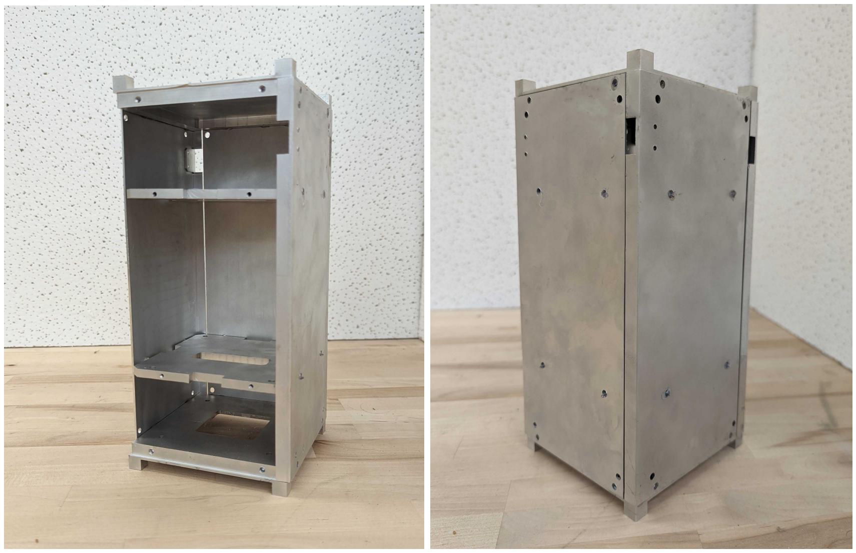

Figure 3. Student-milled aluminium 2U frame with avionics stack bracing

velopment, fostering an environment that promotes learning. The self-supervised nature of some of the technical work on MEMESat-1 allows students to develop leadership skills that contribute to vibrant, inclusive academic and industrial workplaces.

Educational

MEMESat-1 was created with two educational demographics in mind, college undergraduates and K-12 students. For college students, the mission provides educational value through the experience of developing a satellite, whereas K-12 students gain knowledge through interaction with MEMESat-1's payload and BBS.

The central educational advantage of MEMESat-1 is that students are directly involved in all stages of satellite development, as well as mission operations after launch. Designing all of the subsystems in-house gives students the freedom to explore creative solutions to problems, for example, designing and manufacturing the electrical power system using hobbyist COTS components to minimize cost. College students are guided by university faculty and staff, as well as passionate SSRL alumni that volunteer their time to provide technical, programmatic, and operational advice to current members throughout the mission lifetime. In lieu of regulatory bodies, typically provided by the mission sponsor, the MEMESat-1 team utilizes the knowledge and experience of its advisors to help gauge mission constraints, such as bounds for environmental testing or system architecture. Through alumni consultations, students gain insight into the origins and purpose of constraints more than if they were simply provided. However, some tasks are pioneered by undergraduate students who have acquired knowledge of their own through research and experience.

K-12 students are the target demographic of the multimedia engagement aspect of MEMESat-1's mission objectives. They benefit from MEMESat-1 through the opportunity to engage with and learn about satellites. By inviting them to send and receive their memes on their own internet-enabled devices, the need for prior knowledge of special equipment like high-frequency antennas is reduced. An example of direct interaction with MEMESat-1 would be a high school student group building a receive-only ground station, such as a USB SDR and antenna, to send and receive BBS messages. An example of indirect interaction is the use of a publicly available GUI to submit memes, track mission health, and send messages to the satellite. By using memes as a way to grab student interest, MEMESat-1 seizes the opportunity to introduce them to STEM concepts, such as satellite interaction, amateur radio operations, orbital mechanics, and space systems development.

During the final stages of development, before launch, team members will gather resources that introduce concepts relevant to their work on the mission, to be hosted on the MEMESat-1 portal. This act will allow team members to remind themselves what they have learned, how far they have come, and what they have accomplished, passing on the knowledge to the next generation of students.

10. Conclusion

MEMESat-1 consists of a frame, EPS, antenna, OBC system, and passive magnetic attitude control system, all developed in-house. Almost all of MEMESat-1's subsystems are designed and built by University of Georgia students, with the exception of LFR, designed by another collegiate satellite laboratory. This mission serves as an ideal training ground for undergraduates with little to no aerospace industry experience. In addition to serving its own team, MEMESat-1 serves K-12 students by providing a portal to interact with the satellite via the internet. Because this requires no certification, training, or approval, the reach of this mission extends beyond amateur radio users to reach as many students as possible.

MEMESat-1 provides the SSRL with a foundation of proof-of-concept models for an EPS, a passive attitude control system, and a linearly-polarized monopole antenna. Through iterative design, assembly, and testing, the SSRL will have a core bus for future missions, which may be expanded upon and modified as needed. Future applications of this bus expand beyond SSRL into the satellite community so that others can utilize this design for their missions. MEMESat-1 contributes to the future of its members and shares its knowledge and capability with the world.

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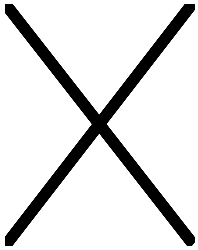

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