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Finding TJREVERB: a Crowdsourced Effort to Find a High School CubeSat

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ABSTRACT

This paper documents the team's process for finding the Thomas Jefferson Research and Education Vehicle for Radio Broadcasts (TJREVERB) with the help of the Amateur Radio community. The team attempted contacting the primary Iridium radio on TJREVERB for one week after it was deployed from the International Space Station but failed. The satellite did switch to its secondary radio, a SATT 4 APRS. However, the team was inexperienced and unprepared to contact the satellite using the SATT 4 APRS. Since we do not have access to an APRS ground station, we leveraged the help of twenty amateur radio volunteers from all around the world to contact TJREVERB. Additionally, many more amateur radio operators contributed their expertise and recorded sightings of TJREVERB using resources such as SatNog's satellite database. This global network of volunteers cooperated to position their respective stations for the best possible chance of contact. This paper discusses how the Amateur Radio community's involvement is invaluable to the students' small satellite education. It also discusses the training program developed due to this experience. The lessons learned about satellite contacts and operations are critically important for future educational satellite teams and will contribute to their success.

Introduction

TJHSST's second satellite, the Thomas Jefferson Research and Education Vehicle for Radio Broadcasts (TJREVERB), is a 2U CubeSat that began as a student-initiated research project in 2016. Its goals are to test the performance of an Iridium 9602N Short Burst Data modem as a communications system for satellites with a SATT4 APRS backup radio, to produce documentation about how high school CubeSat organizations can best operate, and to educate the next generation of engineers and leaders in aerospace. Components of TJREVERB are a mix of space-grade hardware, such as a Clyde Space Electrical Power System; Commercial Off-The-Shelf hardware, such as the Raspberry Pi Zero flight computer; and custom components, such as the flight computer's interface board.

In this paper, we seek to shed more light on the amateur radio community and how future missions can leverage it to communicate with nanosatellites more effectively than using a single ground station. We will use TJREVERB as a case study for this process.

Iridium Radio

TJREVERB was designed to use the Iridium network as its primary mode of communication. For Iridium, the ground station is internet-based and exists solely in software: sending, receiving, and parsing emails to the Iridium service. Each email received from the Iridium service includes an attached message, along with details such as geolocation, time, transaction status, and size. TJREVERB's Iridium ground station consisted of a backend script that parses received emails and stores data in an online Firebase database, and a frontend website that reads and updates from the database. Along with parsing and sending emails, the ground station handles encoding string commands to bytes and decoding incoming bytes to strings and numerical data.

Iridium packets are limited to 340 bytes in length, so data encoding was implemented to save the valuable packet space. While strings were transmitted as ASCII characters, floats and other numerical data would be encoded more efficiently. For example, in commands transmitted to the satellite, the command type was encoded to a single byte and each numerical argument was encoded to three bytes in floating point. A typical number was between 100 and 106, which would require six bytes to write as a string. However, by encoding with a 3-byte floating point, this reduced data usage by 50%. And the equivalent string representation of the header data could range between 11 and 18 characters long, so our more optimal header encoding system saves around 6 to 11 bytes per header. Efficient data encoding like this allows TJREVERB to fit as much information as possible into one Iridium packet.

Automatic Packet Reporting System (APRS)

APRS is a digital mode that allows data to be transmitted on amateur radio bands, those often being the 2m and 70cm amateur radio bands. Oftentimes, APRS takes advantage of frequency shift keying FM to encode data based on a certain codec. Moreover, it is also commonly used for the transmission of positional and text data. Being a packet-based transmission scheme, data is packaged into discrete "packets," as opposed to having an uninterrupted stream of transmission. This allows for packet acknowledgment, the retransmission of lost packets, and the negotiation of nonstandard data rates and formats between stations. Due to the prevalence of APRS, it is able to take advantage of a large network of repeaters in the form of digipeaters, or packet repeaters, which propagate received packets throughout the network. In fact, the SATT4 radio aboard TJREVERB has digipeating functionality that is turned on whenever the satellite is not transmitting APRS packets. This large network of repeaters allows packets to be received across the globe, making it ideal for satellite communications.

Launch and Deployment

Through thousands of hours of collective work, the project went through many design changes before it went from development to testing and final assembly. The team conducted a successful vibration test in Q2 2022, meeting NASA's deadline for mission readiness, and delivered the satellite for integration with TJREVERB's launch provider that July. TJREVERB was launched on the NRCSD 25 SpX-26 International Space Station (ISS) resupply mission on November 26, 2022. It was deployed on December 29, 2022, from the ISS. TJREVERB was deployed together with DanteSat. A total of 8 nanosatellites were deployed in the same batch. Aside from TJREVERB, none of the other satellites used an Iridium or APRS radio.

Space-Track

Before deployment, the team registered TJREVERB with Space-Track, the United States Space Force's online database designed to provide situational awareness of objects in space. Space-Track provided the initial TLE (two-line element) data based on the satellite's deployment. While the TLE was not necessary for the Iridium radio, it proved to be invaluable for the APRS search.

Iridium Search

Immediately after deployment, we sent 3 Iridium messages to be queued into the Iridium constellation. According to regulations, TJREVERB was programmed not to turn on its radio for 30 minutes after deployment from the ISS. Additionally, previous literature and simulations suggested that it would take anywhere between 30 minutes and 6 hours to establish contact with Iridium,[1] so we did not expect an immediate response. However, the team's software-based ground station did not receive contact via Iridium even after one week. We suspect that there was a fault in the team's implementation of the Iridium radio, such as a broken solder joint, causing the radio to fail. Due to the perceived radio silence, TJREVERB switched its main communications to the backup APRS radio.

Crowdsourcing and APRS Search

Since we were not prepared for the implementation of Iridium to fail, we did not invest much time in developing an APRS ground station. Moreover, setting up a ground station at TJ would have been an ordeal, as the team wasn't able to install a directional yagi antenna on the roof of the school to contact the satellite. Due to the unavailability of an APRS Ground Station, the team had to get creative in their attempt to find TJREVERB. The team reached out to the Amateur Radio community to help find the satellite.

The American Radio Relay League (ARRL) sponsors a Teacher Institute. The principal investigator of our team attended the institute and connected with amateur radio enthusiasts from around the United States. When the satellite did not respond using Iridium, she reached out to contacts from ARRL and the Amateur Radio community to help listen for the satellite. Amateur Radio stations, including the historic WA1A in Newington, CT, listened for the satellite as well as operators in Virginia, Maryland, Florida, Arizona, Colorado, New Mexico, California, Washington, Canada, Belgium, Singapore, Taiwan, and Australia. From this process, the team learned the importance of amateur radio in finding and tracking satellites. The team continued to post on social media, specifically LinkedIn and Facebook, to ask for more help. More Hams joined the search, including AMSAT members. Soon, sightings were being reported from all over the world. In addition to the team's crowdsourcing efforts, SatNogs reached out to the team and assisted with finding the satellite.

Finding TJREVERB was difficult without accessible communications. The team used other satellites released in the deployment to estimate the trajectory. This information helped ham radio operators point their antennas to listen for signs of life and attempt contact using APRS. APRS commands were sent but an issue with the naming convention was discovered. The original APRS Radio had been replaced since it was not functional and a replica board was swapped in. The team could not be certain that the proper call sign was assigned to the APRS radio. Therefore, the ham operators sent commands that may not have been properly defined. Unfortunately, none of the commands were successful in contacting TJREVERB.

Lessons Learned: The Importance of Amateur Radio and the Space Community

The team extensively tested the Iridium communication system, but due to overestimating the reliability of their implementation of the Iridium module, they neglected to thoroughly test APRS.

If contact over Iridium was not successful, the satellite was set to switch to the APRS radio for communication. However, the team was not able to establish contact via APRS, since the team did not have a reliable radio station at the school to receive APRS signals. The school's ham radio club had been dissolved due to the pandemic, and the remaining antennae installed on the school's roof were not accessible by the students in the lab. The team attempted to have the antenna moved but remained unsuccessful as it required a continued review by the school system's cyber security department. Thus, an antenna for the ground station was impossible to acquire at the high school in time for the deployment. Additionally, only one student had an Amateur Radio Technician license and thus was the only person qualified to legally operate the satellite on the team. Once the Iridium radio failed, it became evident just how important Amateur radio was to the mission's success.

Amateur radio has a long history with satellite communications. After Sputnik was launched, Amateur Radio enthusiasts tracked the satellite from Earth.[2] Every day, dozens of hams make contact with satellites, listening as they approach and downloading images and data. This data can include weather data, images of the earth from space, and repeated ham signals from satellite repeaters. Because of this, there are numerous stations across the globe already set up for satellite communications. Due to the generosity of the ham radio community, we were able to tap into this community of ground stations to help locate our satellite and attempt to establish contact. Particularly invaluable to making contact was the community behind all of the technical skill in the American Radio Relay League (ARRL). ARRL members attempted to make contact with people across the world, as they offered their time and expertise to help make contact. This worldwide effort compounded the individual capabilities of each ham, merging them together in a scale and quality of collaboration that would be impossible without paying a fee. The amateur radio community's support was a welcome surprise to the TJREVERB team. The team had not expected to receive anything from the satellite. However, the global network produced by the ham radio community allowed the team to achieve something together that would have been impossible to do on their own.

Future Directions: What is old is new again.

Teaching and supporting amateur radio skills is now critical to the team's mission, particularly for new members. The team designed a training program for high school students. The training program helps students understand radio basics, analog electronics, federal regulations on amateur radio, and CubeSat simulators. Through partnerships with ARRL, AMSAT, and local amateur radio clubs, we were able to share this knowledge with freshmen and sophomores in TJ Space, the school club that succeeded TJREVERB. The club's goal is to introduce the basic skills needed to understand satellite communications. The team was successful in getting over 40 students Amateur Radio Technician licenses from the Federal Communications Commission. The team plans to provide opportunities for students to obtain their General and Extra licenses before graduation.

Communications, and by extension radio and ground station knowledge, is one of the most fundamental skills to master for satellites. Satellites by their nature, are devices designed for remote sensing. Because of the great distance between the operator and the device, communications play a key role in data collection. Radio communication is the lifeblood that makes satellites like TJREVERB possible. Having an understanding of how communications are carried out in the field is essential and often taken for granted by students who have never known a time when immediate communications were not available to them. By giving students the opportunity to obtain amateur radio technician licenses, students are learning the fundamentals of radio communication, even if, in their careers, they may be working at significantly higher frequencies for communication. Furthermore, giving students a callsign allows them to explore the ham community on their own and help give back to their community through emergency ham services. Utilizing radio technology is also much more cost-effective than teaching systems engineering, as hardware that is good enough for amateur radio space communication is far less expensive than space-grade components. That, coupled with the importance of radio communication in modern satellite development, is why TJ Space has placed an emphasis on ground station operation in its curriculum.

The team applied for grants and acquired funding to order CubeSat simulator kits from AMSAT. The CubeSatSim kit provides students with a low-cost satellite emulator that they could assemble and program. The simulator runs on solar panels and rechargeable batteries, transmits UHF radio telemetry, has a 3D printed frame, and can be extended with additional sensors and modules, including a camera module.[3] Each kit cost roughly $400 in materials, and while some components were difficult to source, it was relatively simple to place the order with the information AMSAT provides. The simulators (Fig. 1) allow students to experiment with mission and payload design, both physically and digitally. The kits are remarkably modular and customizable, allowing students to design many simple satellite missions. The proximity of the CubeSatSim to the students' laptop ground station also made data transfer much easier compared to a CubeSat, allowing for rapid prototyping and iteration. The editable software base also abstracts away most low-level hardware code, including radio configurations, allowing for a quick start with the platform, even with minimal computer science experience. While actually building a CubeSat can show students more about the industry and can teach physical engineering and assembly techniques, the AMSAT simulators focus more on the planning and development aspects of satellite engineering. Having a predefined base for the satellite lets students spend more time learning effective mission/payload planning, radio, and programming skills while still being able to change the physical aspects of the simulator to suit their chosen mission. Learning these skills helps equip students with the necessary skills to pursue more challenging aerospace projects in the future.

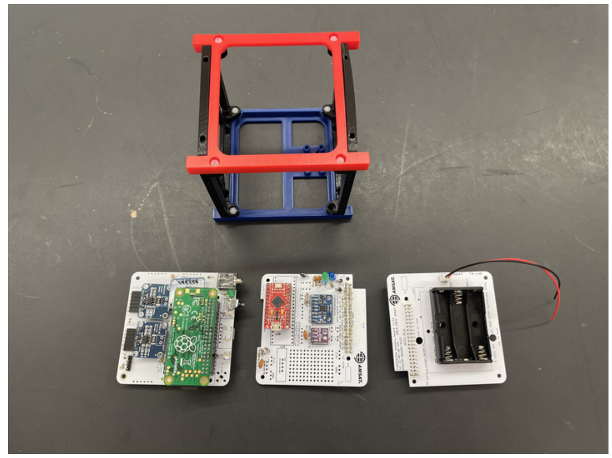

Figure 1: AMSAT CubeSatSim Kit

The students worked with a local Amateur Radio Club to build a 40-meter band receiver using discrete electronic components and a homemade variable inductor (Fig. 2). Through this process, students learned the basics of analog electronics and Radio Frequency signal processing.

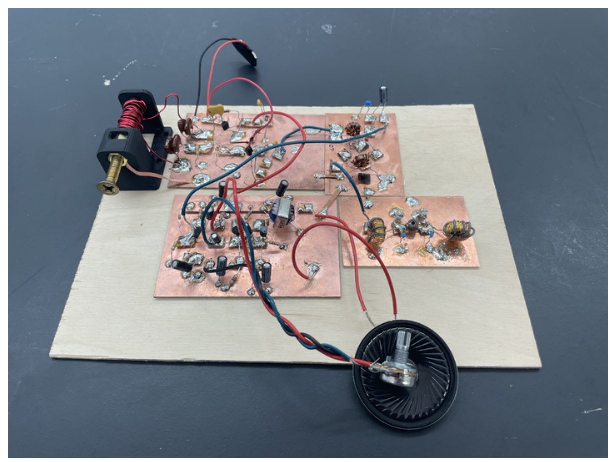

Figure 2: 40m Receiver

While designing, building, and launching a satellite is a goal for students, there is as much to be learned from the contact and operations. Learning about ground stations and radio theory is cost-effective and obtainable for the skill level of most high school students. Exploring satellite communications and operations eliminates the need for a special lab environment or highly specialized mentors. There are many amateur radio clubs ready, willing, and able to help share their expertise and knowledge with students. Connecting amateur radio and space is a path to revitalizing this form of communication and making it relevant to the next generation while teaching valuable physics and engineering skills.

For students who have their amateur radio license and have completed the receiver and the AMSAT, the next level of the program is designing missions for high-altitude balloons. This experience gives students the mission planning and engineering experience of a CubeSat without the formality. High-altitude balloons are an excellent test bed for student missions. It provided the proof of concept needed to develop the next CubeSat mission. The time frame for developing a balloon mission is the course of a school year. It allows students to integrate hardware, software, and communications. Finally, while the team awaits its next opportunity to build a CubeSat, the team is preparing the next generation of students by designing and launching missions from high-altitude weather balloons. By making use of the skills the team has acquired through the radio receiver and AMSAT projects, the team is launching a weather balloon with a radio spectrum analyzer.

Conclusion

The experience of designing, building, launching, deploying, finding, and operating a CubeSat has been formative for the CubeSat team of the Thomas Jefferson High School for Science and Technology. The team has learned the entire mission process from conception to operations. There are many facets to CubeSats that students can explore further in their educational and professional careers including aerospace engineering, program management, mission planning, computer aided design, electrical engineering, computer programming, testing and simulation, regulatory compliance, telecommunications, launch services, and satellite operations. This experience has led the team to design a training program for other high school students interested in a practical, hands-on opportunity working with satellites. The team hopes the program will spark curiosity and inspire others to consider a future career in aerospace.

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