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From Development Through Re-Entry: CTIM Operational Lessons Learned and Successes

Sierra Flynn, Gabe Bershenyi, Brian Boyle, Dave Harber, Beth Cervelli, Scott Gennari, Adalyn Fyhrie, Adrienne Pickerill, Jacob Sprunk, Karen Bryant, Cody Folgmann
University of Colorado - Laboratory for Atmospheric and Space Physics (LASP)
1234 Innovation Dr, Boulder, CO 80303, USA; 303-882-7677
sierra.flynn@lasp.colorado.edu

ABSTRACT

The University of Colorado's Laboratory for Atmospheric and Space Physics' (CU-LASP) Compact Total Irradiance Monitor (CTIM) SmallSat mission was a 6U CubeSat designed full-cycle and in-house between 2018-2022 and flew for 1.5 years after launch until re-entry, overshooting the 1-year mission lifetime goal. CTIM's primary mission was to measure the total irradiance of the Sun, with ancillary measurements of the night-side Earth IR radiance, while demonstrating new technological capabilities of silicon-substrate room temperature vertically aligned carbon nanotube (VACNT) bolometers. The instrument was based on the Total Irradiance Monitor design that flew on SORCE (2003), TCTE (2013), and TSIS (2017). CTIM successfully continued the 40-year, uninterrupted measurements of total solar irradiance (TSI) with 0.017% measurement uncertainty. CTIM also hosted the first LASP-built spacecraft bus using the LASP Common Code flight software suite. Upon launch, commissioning was fast and efficient despite not having a GPS unit onboard to assist with spacecraft identification and ground station pass planning. All subsystems performed nominally throughout the mission with a few small hiccups requiring operational workarounds. Thanks to the establishment of automated ground station interfacing, command-and-control, and data processing and ingest, CTIM was able to perform at near-maximum efficiency using reduced staffing during the two months prior to re-entry. Future LASP SmallSat missions utilizing the CTIM bus and FSW designs will benefit from the CTIM "lessons learned" assessment. The most impactful lesson learned came from a series of undervoltage events seen early in flight due to a lack of power analysis and planning tool bugs. The half-duplexity of the UHF antenna, flash corruptions, and interface lockups created operational challenges as well. LASP demonstrated a highly successful in-house bus while CTIM successfully continued the TSI Climate Data Record. The lessons learned will pave the way for more low-cost missions to continue these important measurements into the future.

INTRODUCTION

The CTIM Mission

The Compact Total Irradiance Monitor (CTIM) was a 6U CubeSat that measured the total irradiance of the Sun. CTIM was based on the TIM designs of SORCE-TIM (2003), TCTE-TIM (2013), and TSIS-TIM (2017), and continued the 40-year, uninterrupted measurements of total solar irradiance (TSI). CTIM utilized novel silicon-substrate room temperature vertically aligned carbon nanotube (VACNT) bolometers, demonstrating next-generation technology. The CSIM sister-mission has proven that the required levels of thermal stability are possible on a CubeSat, opening the door for other thermally dependent CubeSat missions like CTIM. The CTIM mission launched July 2nd, 2022, into a 500km, 45-degree inclination orbit, with a 1-year mission goal, but continued successfully operating until re-entry in early December 2023.

LASP

The University of Colorado's Laboratory for Atmospheric and Space Physics (CU-LASP) is a full-cycle space mission development laboratory. Originally founded as the Upper Air Laboratory (UAL), it was established before NASA in 1948. LASP consists of 950 employees throughout its Science, Engineering, and MO&DS (Mission Operations and Data Systems) divisions. LASP led CTIM's overall system design, bus and flight software development, science instrument development, integration and test (I&T), mission operations, and science data analysis. The laboratory's teams are highly experienced and collaborative, leading to significant mission successes, particularly in the SmallSat realm. Because of CTIM's successes, as well as those of other SmallSat missions designed at LASP (e.g., CSIM, CUTE, CIRBE), LASP was granted the "COSPAR Center of Excellence for Capacity Building in CubeSat Technologies" award in 2024 for outstanding SmallSat design, science, and operations[1].

LASP has one of the best student mission operations training programs in the nation. We employ around 20 graduate and undergraduate CU students on our Space Flight Operations (SFO) Team. Our operations students complete a rigorous 4-month training program to certify in mission operations. They are taught by experts in the field about LASP's missions, operations philosophies, programming practices, systems engineering concepts, hardware safety, software security, and technical subsystem training[2]. This training program has been curated and taught annually since the 1980's, with a SmallSat-specific segment, the SmallSat Operations Team (SMOPS), integrating in 2018 with the start of the CSIM mission. The SMOPS team is unique among LASP's other Mission Operations Teams in that it depends heavily on student involvement and nearly-autonomous ground operations. LASP's collaborative nature in the SmallSat realm has encouraged operations students to work closely with professional scientists and engineers to aid in mission management, development, integration and test (I&T), science data processing, ground station management, and more[3,4]. This heritage has significantly contributed to the operational successes of dozens of LASP missions, including CTIM.

Satellite Design

The CTIM bus was the first-ever LASP-built bus using LASP Common Code (LCC) as the command and data handling (C&DH) flight software (FSW), distinguishing it from older LASP SmallSat missions (MINXSS, CSIM, CUTE, and CIRBE) which used a Blue Canyon Technologies (BCT) XB1 bus. The CTIM attitude determination and control (ADCS) unit, the XACT, was designed by BCT and contains the standard ADCS subsystems (3 coarse sun sensors, 4 magnetometers, 3 reaction wheels, 1 star tracker, 3 torque rods, 1 IMU, but no GPS). The TIM (total irradiance monitor) instrument also uses LCC FSW and contains 2 instrument heads/detectors, each containing 4 channels/cavities with shutters. CTIM also has 2 batteries, 2 solar arrays, heaters, a UHF antenna for real-time uplink and state-of-health downlink (beaconing), and an S-Band radio for science data playbacks.

CTIM Operations

Ground station operations of the UHF and S-Band antennas are run autonomously at LASP. Routine flight operations are also performed autonomously by special procedures running in the command-and-control application, OASIS-CC. For anomalous or special activities, the LASP Operations team, mostly composed of students, can access this interface remotely. This set-up allows for highly efficient operations[5].

CTIM CONOPs are relatively complex. Normal science involves fine sun pointing while cycling different sets of shutters, collecting solar irradiance data. On a weekly, bi-weekly, and monthly cadence, the extra shutters will cycle to provide calibration data. Every eclipse, the spacecraft re-orients the instrument towards nadir or zenith to take ancillary Earth or deep space measurements. Additionally, CTIM establishes 10-minute real-time contacts with the UHF antennas at LASP for commanding and telemetry capabilities. A huge benefit of being in the amateur band was that it enabled 276 members of the amateur radio community (SatNOGS) to capture a total of 1.4 million UHF frames throughout the mission[6]. On high-elevation LASP passes, CTIM executed S-Band playbacks of science data and a small set of back-orbit housekeeping data (~3-4 downlinks per day). These activities were wrapped up in relatively-timed sequences (RTSs) called by an absolute timed sequence (ATS), the latter of which was created weekly and loaded autonomously.

The CTIM mission (2022) was launched around 2 other "generation 1" SmallSats: CUTE (2021) and CIRBE (2023). The operational successes and lessons learned from the CTIM mission have benefited these missions and will be applied to LASP's fleet of future SmallSats: AEPEX (2024), SPRITE (2025), CANVAS (2025), COSMO (2025), DYNAGLO (2026), OWLS (2026), MANTIS (2026), and more. In this paper, we discuss the successes and lessons learned from a mission operations perceptive, from CTIM development through re-entry. The goal is to not only improve our own operational processes, but also to share our experiences with new principal investigators (PIs) and project managers (PMs) in other SFO facilities to help establish low-cost SmallSats as a viable and highly successful option for future science mission vehicles.

PHASE C/D: DEVELOPMENT

Commanding and Operations Philosophy

For a typical mission, operators may not have the in-depth understanding of the spacecraft's software or hardware like a project engineer would. Thus, operational processes and scripts should be "fool-proof" and as automated as possible, so that operators do not need to spend valuable time investigating telemetry or searching for commands during time-sensitive activities. This point is even more important for a student-heavy operations team like SMOPS.

To accomplish this goal, the operations team started by documenting CTIM's 416 command definitions, constraints, idiosyncrasies, and telemetry responses in a command and telemetry database (CTDB) with inputs from the flight software and engineering teams. This spreadsheet was then fed through a tool to automatically build 416 command wrapper scripts which automatically checked telemetry before and after each command, such as command counters or expected state changes, and included logic to re-try commands (if safe to do so) if OASIS-CC was running in automated (non-manual) command mode. These procedures significantly improved the automatability of CTIM operations (during both the I&T phase and flight) by leaving the command re-attempts and telemetry verifications up to the system instead of an operator.

Testing Philosophy

The LASP SmallSat Teams believe in "**fly like you test, and test like you fly**" and “**test early and test often**”. Due to the fast-paced and low-budgeted nature of SmallSat programs, this can be a hard mantra to stick to. However, it is crucial to follow in order to increase the chance of mission success and even out the operations workload in the long run. Over the last decade, this philosophy has led to the LASP SmallSat program successfully operating all 8 of its SmallSat missions, each producing valuable scientific data.

After providing crucial information for the mission requirements, budget, and schedule, as well as valuable feedback during mission PDR and CDR, the SMOPS team really starts to get involved with development. This typically happens when the flight software team has finalized 90%+ of their LCC software suite, at which point they provide command and telemetry definitions to the Operations Team. On CTIM, SMOPS started significantly contributing to the development phase a year before launch. This allowed us to be heavily involved with the I&T phase using our flight command-and-control suite and provide valuable feedback to the flight software and engineering teams when we experienced test failures. Flight rules, idiosyncrasies, and standard operating procedures (SOPs) were documented at these early stages as well.

SMOPS used the test design philosophy from CSIM, CUTE, and CIRBE to apply to CTIM I&T. Because of similarities between these missions, many thoroughly-tested and verified scripts were re-used and tailored to CTIM, decreasing I&T workload and risk.

The **aliveness tests** tested the basic electrical and command/data paths between the bus and its subsystems. These helped our teams establish an understanding of subsystem behavior and how the 5,000+ telemetry items were distributed amongst CTIM’s 90+ packets, and the resulting scripts were used as building blocks in the **Comprehensive Performance Test (CPT).** This day-long test verified the complete functionality and subsystem interfaces. We ran these in-between every environmental test (vibe, TVAC, air bearing, etc.). A baseline CPT run at the beginning and end of environmentals showed that the system had not unexpectedly changed during those tests.

LASP houses a small **air bearing** table in a lab with a **heliostat**. This set-up allowed us to sit CTIM on an air-hockey-like table and confirm the expected ADCS behavior as it tried to point the solar arrays at the Sun or at an off-pointed angle. Testing CTIM on 2 axes was an easy way to verify the polarity of the ADCS components (i.e., the coordinate frame mappings of each component as mapped in FSW vs. how they were installed) and the behavior of our planned science attitudes. For CTIM, this crucial test revealed that the harnessing between the XACT and C&DH bus was not secure, and revealed that we did not have engineering conversions or limits on our ADCS telemetry, prompting us to immediately fix these issues early on.

LASP also houses 4 **TVAC (thermal vacuum)** chambers, which the SmallSat teams use for 14 days of continuous operations while thermal cycling in a space-like atmosphere. Since this test requires months of preparations like scripting and CONOPs development, it is a great way for the SMOPS team to get “ahead” of the workload that tends to increase closer to launch while testing the system to its limits. The 2nd week of TVAC was reserved for 24/7 **DITL (day-in-the-life)** operations, during which students practiced generating and uploading ATSs over UHF while the spacecraft performed science and downlinked data over S-Band. This test helped the SMOPS team understand the system behavior, and subsequently upgrade the database limits and automated alerting system to a flight-like state. While running ATSs and RTSs in parallel, the SMOPS team developed a crucial understanding of the LCC sequencing engine, including its idiosyncrasies and limitations (e.g., if a sequence is called in the same engine as an active sequence, the latter will be halted, which could lead to an unsafe configuration). Unfortunately, the flexibility of the sequence engine led the operations team to make this same mistake in flight: CTIM undervoltaged 3 months after launch due to an operator starting an S-Band sequence while the ATS was running; post-pass, the ATS caused the S-Band sequence to terminate before it turned off the S-Band. This caused the S-Band to stay on, so battery voltage slowly dropped, and about 7 hours later the spacecraft reset due to low power. Additional day-in-the-life testing could have helped prevent this in-flight anomaly from occurring.

One of the major benefits of integrating the mission operations center (MOC) with the primary ground station (GS) is the flexibility of running multiple **end-to-end tests** whenever needed (constrained by the higher-priority pre-scheduled flight passes). This test is required to verify the entire uplink and downlink paths, from the actual LASP ground station, over RF waves, to the spacecraft's antennas, radios, and subsystems. Typically, commandability and telemetry will be verified through these systems, as well as S-Band downlinks and decoding. Downlink noise, packet rates, and half duplex complexities will be assessed. On CTIM, deciding on which packets we should get in real-time and at what rates was crucial, because we had over 90 packets and a half-duplex antenna, meaning the ground and spacecraft antennas could not transmit or receive data at the same time, resulting in frequent lost packets and/or commands if the telemetry rate was too high. One other challenge of operating over UHF is that our antenna wrapped packets in AX.25 headers constrained to 256 bytes, a feature not present on the hardline telemetry path typically used during other tests. Initially, our system was not set up to account for how CTIM's UHF antenna segmented larger packets, resulting in certain packets never being decoded. Fortunately, we caught this during early end-to-end testing and fixed it prior to flight. The S-Band testing was crucial to understanding the theoretical link budget of the system versus the actual capabilities in-practice. The GS team was able to characterize S-Band noise and improve the ground decoding software to compensate in real-time. The end-to-end tests were also a great way to assess the write-versus-read rates of onboard storage; fortunately, our multiple daily S-Band passes were plenty to keep up with the onboard storage rates, so we did not have to worry too much about when the storage partitions would roll over and start overwriting older data. Nonetheless, this experience encouraged us to create tools and processes to quickly re-dump old data in flight when needed.

The Implications of Cutting Costs

One of the biggest reasons that PIs and PMs should involve the Operations team early on in development is so that we can assess the operational impacts from science and engineering decisions. At LASP, the SMOPS team has dealt with an increase in operational complexities and cost because of the following design decisions:

Star Trackers

To cut costs, all of our SmallSat missions, including CTIM, have opted to only install one star tracker. The XB1/XACT star trackers have large keep-out zones near the Sun and Earth that can be hard to avoid depending on the desired mission science attitude. With only one star tracker, the attitude solution is frequently "lost" when the tracker is blinded by the Sun or Earth. This means these missions can expect frequent sun-safe regressions (typically 1 per week on CSIM, CTIM, CIRBE, and CUTE). The operations team needs to determine an efficient way to recover from these. Fortunately, the CTIM Operations Team utilized heritage automated safemode recovery scripts from CSIM (2018) to recover the spacecraft and instrument, return to fine science pointing, and continue taking science data within an hour of the first LASP overflight post-safing. While most anomalies should require operator intervention to assess spacecraft health before attempting recovery, the prevalence of these "normal" and expected sun-pointing events have given us enough experience to design automated procedures that verify spacecraft health before taking action (i.e., an abnormal sun-safing event, or one that comes with additional faults or anomalous telemetry, stops automation and alerts the on-call operator that manual intervention is needed to assess and recover the spacecraft).

Storage Radiation Tolerance

Nearly all of our satellites flying both SD cards and NAND FLASH have experienced multiple storage corruptions severe enough to warrant occasional on-orbit reformats. These are thought to be due to the low radiation tolerance of these COTS components. The operations team should know how to quickly assess the storage state in case any mission data is salvageable before wiping the storage partitions with a reformat and returning to normal science taking operations as quickly as possible. On CTIM, the lessons learned from several of these in-flight anomalies will benefit future LCC missions, as discussed in the "flash corruptions" and "safing events and resets" sections below.

Shutters

Fortunately, CTIM was equipped with shutters that could be closed when in hazardous environments (e.g. instrument pointing in the ram direction). Some missions may opt to cut costs by removing these safety components, but in doing so they may be putting a huge challenge on the operations team. PIs should assess environmental risks and probabilities of impact on their instruments. For spacecraft with a COTS ADCS component, like CTIM's XACT, the operations team may not have full visibility or control of the ADCS algorithms which could inadvertently point an exposed instrument at a degradation source.

GPS

CTIM was the first SmallSat in years that the SMOPS team flew without an onboard GPS for time and position information. Fortunately, the team had experience developing automated ground-in-the-loop (GITL) workarounds after both CSIM's and CIRBE's GPS units suddenly failed. Every pass, the latest TLE is pulled from Celestrak to load the current ephemeris and UTC ground time to CTIM. It is important to note that this method can only be accurate to within a couple seconds, which was suitable for CTIM's 10-second science accuracy requirements. If higher timing or positional accuracy is needed, either a costly time correlation assessment must be done and implemented, or a GPS unit (or two for redundancy, given their failure rates) should be installed.

Delayed FSW

With small mission costs, tight schedules, and fewer requirements comes the inevitability that flight software will not be 100% ready and frozen by the I&T phase. It is crucial that operations teams prepare for this possibility and remain flexible in their procedural design and testing plans to account for this. One of the biggest challenges for the CTIM Team leading up to delivery was the lack of flight software resources needed to design robust fault protection. Due to resource and schedule constraints, CTIM's systems engineer had to quickly but carefully design the spacecraft's anomaly "watchpoint" triggers and sequenced responses a few weeks prior to delivery. Once finalized, the SMOPS Team did not have adequate time to thoroughly test these, and so CTIM flew with untested fault protection running. This led to two undervoltages early in flight because the software undervoltage limit was inadvertently set lower than the hardware undervoltage limit, so the spacecraft browned-out before safing itself. Another fault protection oversight was that if the XACT went into sun-point, the C&DH would continue operating like normal, e.g. assuming the instrument was pointed at a science source and continuing to take data despite the anomalous ADCS state. Once we realized these issues, they were promptly fixed, but it did result in a small loss of science data and potentially long-term battery and/or instrument degradation. Both issues could have been identified and fixed with more fault protection testing pre-launch. Fortunately, most of CTIM's fault protection design is universal to the LCC bus, and so can be applied and iteratively improved upon for future LCC missions like AEPEX, SPRITE, and CANVAS.

Ground Stations & Support Equipment

Another cost cutting decision may be to decide not to implement system redundancy or back-ups. While the consequences of single point failures in a spacecraft system may be well understood, the same should be carefully considered on the ground side. For example, PIs should weigh the risks of: only having one ground antenna available to them; whether or not the ground system is running on a UPS; and/or what to expect when there are no command-and-control backup systems. No matter how robust the spacecraft is, these ground system risks can lead to long down times, significant loss of data, or even contribute to early end of mission. At LASP, fortunately these decisions did not impact our generation 1 SmallSats significantly, but nonetheless we decided to add additional ground stations to our network and automate system back-ups for future SmallSats.

Test Hardware (FlatSats)

The importance of having a test until available to the SMOPS Team cannot be overstated. The CTIM team built out their FlatSat early on in development, allowing teams to work congruently on both the test and flight units, thus enabling them to meet project deadlines, test complex or hazardous procedures, replicate anomalies, and help resolve said anomalies. A secondary benefit is the possibility that a piece of flight hardware may break during I&T, so having a second component readily available from the testing unit may save the mission.

PHASE E: FLIGHT OPERATIONS

Commissioning

After a successful development and testing campaign, CTIM launched on Virgin Orbit's LauncherOne rocket on the "Straight Up" mission along with 6 other CubeSats on July 2nd, 2022. Despite CTIM having no GPS for automatic time and position knowledge, by the second LASP overflight that day, we were able to confirm command and telemetry receipt with the spacecraft. On the next 2 passes, we successfully verified deployments and state-of-health, synced spacecraft time and ephemeris, and loaded post-deployment sequences. However, about a day after launch, CTIM and the other 6 satellites started drifting far enough from their initial post-deployment TLEs that LASP could no longer command nor receive telemetry. Fortunately, the SatNOGS community helped us zone in on a different TLE, and we were able to communicate with CTIM again. Without SatNOGS, we would have been relying on the inaccurate TLE provided by Virgin Orbit and Celestrak for the next 11 days until the issue was corrected, and so would have been unable to communicate with our spacecraft during that time.

Within 4 days of launch, we had fully commissioned the C&DH bus, XACT ADCS unit, *and* the instrument – the spacecraft was in a nominal, science pointing configuration! This commissioning period completed twice as fast as our 2 previously commissioned SmallSat missions, despite having no GPS onboard. This fast and efficient commissioning couldn't have been possible without the carefully designed DITL and end-to-end tests we performed before delivery. It took us several extra days to perform storage downlinks via S-Band and iron out the data paths on the ground system side. After that, we had 3 weeks of refining the instrument using first-light cruciform scans and calibrations.

SatNOGS Collaboration

Clearly, building a strong relationship with the amateur radio community is invaluable during early-orbit operations. We started building this relationship a couple months prior to launch, when our ground station engineer started engaging with the amateur radio community (SatNOGS). Since CTIM was operating in the amateur band, we published the UHF radio configuration and beacon packet definitions, and created a CTIM dashboard on the SatNOGS website where the hundreds of amateur radio operators around the world could upload their captured CTIM packets in real-time. In addition to early TLE and beacon identification, the SatNOGS community has provided invaluable support throughout the mission lifetime, including early anomaly detection and re-entry support[6].

Flash Corruptions

CTIM continued operating nominally until January 2023, about a half year after launch. At that time, CTIM started experiencing occasional CDH NAND FLASH corruptions, all with slightly different symptoms and issues that all required full reformats. The most notable common symptom was that read/write pointers started behaving erratically, writing data to the wrong partitions and in the wrong orders, or causing the read pointer to increment when we were not doing playbacks. We could not have anticipated this type of anomaly, and likely would not have seen it with any more ground testing, since it may have been radiation-induced. Fortunately, our procedures were mature enough at this point that we were able to quickly reformat NAND FLASH after recovering as much data as possible before returning to normal operations. These experiences are helping our electrical engineers build more robust memory cards and FPGAs for future SmallSat missions.

Safing Events and Resets

SmallSats in LEO typically experience radiation hits from high-energy solar and geomagnetic particles. These radiation hits can lead to storage corruptions (as noted earlier), subsystem interface lock-ups (a few CDH-to-XACT and CDH-to-payload lock-up were observed on CTIM), and also single event upsets (SEUs), all of which can lead to resets of the C&DH bus, XACT, and/or instrument. On CTIM, it was imperative to create and test efficient recovery procedures for these components pre-launch, which sped up recovery times when they inevitably occurred in flight.

Throughout the 500-day CTIM mission, we gathered critical statistics on the number and impacts of resets. In flight, the LASP CDH bus reset every 40 days on average. Conversely, On CSIM, CUTE, and CIRBE, the BCT XB1 bus experienced a reset about once a week. It is important to note that CTIM was in a lower-inclination orbit with less radiation.

PHASE F: END OF MISSION

Hiatus ATS

Due to delayed funding for the CTIM mission extension, the SMOPS team had to suddenly prepare for a period of low-cost operations in September 2023. Within four days of this announcement, the SMOPS team drafted a “lights out” minimal operations plan for the remainder of the mission, loaded as a month-long “hiatus” ATS to CTIM, cutting operational costs by 75%. Since most of our processes were automated at this point, and our planning tools were modular and flexible, this was not a problem for us. We were able to continue primary TSI science while dumping data 4 times per day without much manual operations support.

Re-entry and Community Involvement

While the team re-ran re-entry predicts every few months or so after launch, we could not have predicted the effect that the strong geomagnetic weather causing increased atmospheric drag in 2022 could have on our mission lifetime. The CTIM team was expecting a re-entry date around April 2024 per STK analysis. However, each week starting in mid-November, when the ground station schedule and onboard ATS was nearing the end of their planned week (i.e. running off of a TLE from 5-7 days earlier), we started experiencing timing delays in our predicted AOS and LOS times, as well as a steady increase in S-Band noise. After a couple weeks of this, we realized it wasn’t a one-off bad TLE, but it was actually due to the spacecraft’s orbit decaying more rapidly. We re-ran our re-entry predicts and realized we only had 3 weeks of the mission left, 5 months earlier than the most recent analysis suggested!

Fortunately, we were able to schedule final calibrations, data redumps, and even have CTIM “sing” a goodbye song in ASCII that was decoded by amateur radio operators in the United States, Turkiye, Hungary, and Greece before CTIM recentered the atmosphere above Hawaii on December 3rd 2023[7,8]. This was a wonderful way to collaborate with the community and bade farewell to our highly successful SmallSat mission.

CONCLUSION

The CTIM mission overshot mission requirements and expectations[9]. Much of these successes can be attributed to LASP’s culture of collaboration and sharing lessons learned in a positive light. LASP has annually taught and certified a cohort of undergraduate students on the space flight operations team since the 1980’s, and these students have contributed significantly to the successes we've seen in our SmallSat Operations since 2012. LASP will continue to curate the SmallSat Test Plan, emphasizing the importance of completing CPTs, air bearing, TVAC, and end-to-end tests pre-launch to greatly increase the chance of mission success. The iterative improvements we've made to our automation software on both the Ground Station and Mission Operations sides have greatly reduced risk and project cost. Additionally, the first LASP C&DH bus used on CTIM was highly successful, with many lessons learned shared and applied to our future missions, AEPEX (2024), SPRITE (2025), CANVAS (2025), COSMO (2025), DYNAGLO (2026), OWLS (2026), MANTIS (2026), and more. We hope that these lessons learned will contribute to the growth and successes of the SmallSat realm in the future.

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