SSC19-WP1-03

Development of a High-Altitude Balloon CubeSat Platform for Small Satellite Education and Research

Jill Davis, Alex Reynolds, Yezad Anklesaria, Henry Pernicka, Jillian Schmidt
Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology
400 West 13th Street, Rolla, MO 65409-0050

ABSTRACT

The Missouri University of Science and Technology Satellite Research Team began its high-altitude balloon program as a high school summer camp in 2014. Since then, a new course has been added to the Aerospace Engineering curriculum, where students fly "BalloonSat" payloads to altitudes of ∼100,000 feet. In order to enhance the educational outcomes and enable advanced SmallSat research, the BalloonSat payloads have been redesigned into a CubeSat form-factor payload to replace the previous high SWaP design. As new CubeSat teams may face technical challenges and daunting regulations, the "BalloonCubeSat" concept enables groups to test CubeSat systems and build their programs before attempting a launch to Earth orbit. This approach facilitates more launch opportunities at a reduced cost. The proposed BalloonCubeSat design conforms to the standard 1U CubeSat form factor, and employs an Arduino Uno or Raspberry Pi as the OBC. The payload PCB stack leverages the PC/104 header, and as the program develops it can serve as a platform for COTS component testing and a testbed for advanced mission concepts. It is anticipated that merging BalloonSat and CubeSat programs will increase the educational impact on students by enabling reduced-cost launches and providing an intermediate platform for SmallSat research, testing, and innovation.

INTRODUCTION

The Missouri University of Science and Technology Satellite Research Team began its high altitude balloon to give prospective aerospace engineering students a glimpse into the space systems engineering process by flying payloads ("BalloonSats") they built to near space, collecting data and images along the way. With initial successes, the program was quickly expanded to include an experimental college sophomore-level course. The motivation for developing the course was to provide hands-on experiential learning to better prepare students for their aerospace senior design culminating experience. The two credit hour course was offered as a free elective for aerospace engineering students with a maximum enrollment of 30 students. Students in the course proposed a flight experiment that fit within the given launch constraints including payload mass, volume, and power usage. The payloads varied widely from high altitude biology experiments to attitude stabilization and control. With continued success, the BalloonSat hardware architecture was revised for the ease of integrating a variety of sensors that would function with a standard flight computer, the Arduino UNO. Starting in Spring 2019, the Missouri S&T Aerospace Engineering program integrated the course into the curriculum as a required sophomore-level design class (AE 2790) in which students design, build, test, and fly a BalloonSat payload to altitudes of ∼100,000 feet. The evolving course curriculum introduces students to various satellite subsystems and collaborative project management by paralleling the development cycle of a university-level microsatellite. Students select from an approved list of sensors to fly on their BalloonSat payloads and then define their mission goals and requirements.

The original BalloonSat design can be seen in Fig.1. The structure of the box was constructed from foam core and had an additional layer of thermal insulation foam. The payload included an Arduino Uno flight computer, a sensor interface shield board, an integrated pressure and temperature sensor, a controllable heater, and an activation switch board with a thermistor to record the external temperature. It also included a battery pack composed of standard nine volt batteries, where the number of batteries flown could be changed depending on how many additional sensors were flown. Additionally, each box was equipped with either a photo or video camera. The total box weight was approximately 700 grams. As shown in the figure, this design secured the BalloonSat payloads to the balloon flight string via a hole placed in the middle of the box and the "flight interface connection" (a section of polypropylene tubing).

Figure 1: Original BalloonSat Payload Design

As the high school summer camp and AE 2790 enrollment have continued to grow (up to 48 in the summer camp and 70 in the class), the number of payloads flown per flight has also increased. While this is a very positive development in terms of the number of students reached and the amount of data collected, it poses a challenge to the launch logistics. Additional payloads increase the overall weight to be lifted to the target science altitude of 100,000 ft. One solution would be to fly a larger balloon. However, with the facilities and staff available for launch, a larger balloon would be too cumbersome to fill and manage. A larger balloon also poses additional safety risks to the filling crew as more hydrogen (and time) is needed to fill the balloon. Another solution is to decrease the individual payload mass. This could be done by removing sensors to lower the power draw or even by removing cameras from some of the payloads, but this limits the educational value of each BalloonSat payload. Removing sensors reduces students' exposure to a variety of interface types (such as I^2C and analog), and while the cameras are not the primary sensors, they enable students to correlate the data they have collected with video and photos of the phenomena recorded during the flight.

In order to reduce the individual payload mass while maintaining and increasing the educational value to students, the BalloonSat payloads have been redesigned to mimic the CubeSat form factor. Shown in Fig. 2 , the revised payloads are secured to the flight string via an interface connection mounted on an outer corner of the box. This adjustment enabled the box size to be reduced to have internal dimensions consistent with the CubeSat format standard that supports PC 104 PCBs. The new payload is shown side-by-side with the old payload in Figs. 3 & 4. The BalloonCubeSat is composed of two PCBs, a power board and a flight computer board that houses the Arduino UNO flight computer. The boards are connected via PC 104 headers and secured with nylon standoffs. The nine volt battery pack was replaced with a pack of AA batteries, and the larger photo and video cameras were updated with a much smaller camera that can be configured by the flight computer to take photos or video during the flight. In addition to this new "educational" payload, a "research" payload was designed to support the test of small satellite technologies by using the same power board but upgrading the flight computer board to interface with a Raspberry Pi Model 3B flight computer.

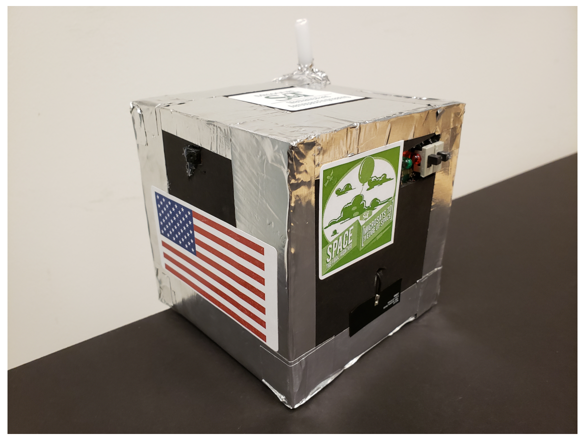

Figure 2: Fully Integrated BalloonCubeSat Payload

Figure 3: Payload Comparison Side View

Figure 4: Payload Comparison Top-Down View

LITERATURE REVIEW

High altitude ballooning has been a relatively cheap option for launching payloads to near space for some time by amateur radio groups and hobbyists, university researchers, and a variety of educational groups. High altitude balloon flights can be done by almost anyone, and in most cases in the United States, only require launch permission from the FAA. Many of these groups also participate in STEM outreach initiatives involving high altitude balloons and many offer launch assistance. Furthermore, there are a variety of commercial entities offering launch assistance programs, such as Stratostar and Launch With Us, that provide the launch facilities, supplies, and tracking equipment.[1,2] Some groups even offer the payloads as kits with education curriculum materials to guide educators through the high altitude balloon payload build process. Most of these programs provide flights for roughly $1,000 per launch, depending on the payload size and complexity.

The CubeSat "revolution" has also made launching spacecraft into orbit a reachable goal for many of the same groups that conduct high altitude balloon launches, primarily amateur radio groups and hobbyists, university research teams, and educational groups. With the availability of COTS CubeSat components, these groups have been able to design, build, and launch spacecraft into orbit with comparatively modest budgets. Additionally, many commercial CubeSat component providers offer CubeSat "kits" that include all major subsystem components and flight software, where additional payload components can be optionally added on a user basis.[3,4] While these programs are making launching a satellite into space more accessible to first time CubeSat developers, they are still quite expensive. Programs such as ThinSat provide similar kits on a much smaller scale, enabling groups to launch payloads for approximately $30,000.[5] However, Swartwout[6] reports that the mission success rate for university CubeSats is still quite low. An important note is that teams who launch multiple CubeSats (designated as "prolific" schools) tend to increase their success rate, most likely due to the fact that they can apply lessons learned from previous launches. While this "learn by failure" approach is slowly increasing the mission success rates for prolific schools, it makes it extremely expensive in terms of time and costs for new CubeSat teams to reach their first successful mission. There are many other educational and outreach programs that guide students through the CubeSat design, build and test process, such as the HEPTA-Sat Training Program.[7] These programs are excellent in terms of exposing students to the development of CubeSat concepts and techniques, but the end products of these programs are not launched.

The Missouri S&T BalloonSat program has implemented a design concept that merges these two STEM education tools. A new BalloonCubeSat payload accommodates the PC/104 standard for CubeSat components, and enables new CubeSat teams to build their knowledge and experience using a lower risk and lower cost platform. The payloads, like COTS CubeSat components, are modular with flexibility to swap components in and out depending on mission-specific requirements. The same EPS can be used to support multiple flight computer boards, enabling a variety of mission complexity levels. These mission concepts can range from introductory hands-on STEM learning experiences for junior high and high school students, or CubeSat flight systems tests in a dynamic near-space environment. The BalloonCubeSat concept pairs the educational experience of designing and integrating a low SWaP spacecraft with the affordability of high altitude balloon launching. While this concept has been explored before by private companies[8] and NASA,[9] these programs were still relatively expensive and did not have standardized designs.

TECHNICAL OVERVIEW

Research and Educational Payloads

The research and educational payloads each consist of two or more PC/104 boards stacked inside a 1U form-factor structure. The highly standardized PC/104 specification consists of a universal header and allows for flexibility in mission design. The payload structure consists of an inner layer, made of insulating foam to protect components from the low

temperatures experienced at higher altitudes and an outer layer of foam core that provides structural support.

The modular, flexible design employed by Missouri S&T allows both payloads to be powered by the same power module. This power module includes six AA batteries aligned in series to supply an unregulated 9 V to the board. Depending on mission requirements, the user can select if they want the power module to supply regulated 3.3 V and 5 V rails by simply soldering (or not soldering) the voltage regulation circuitry. It is noted that the educational payload functions without the power module voltage regulation circuitry, while the research payload does not. This circuitry has an associated high technical difficulty and risk level, and the educational payloads are therefore specifically designed to operate without voltage regulation. However, the circuitry can be optionally populated should the need arise.

The primary difference between the educational and research payloads is the flight computer module. The research payload, as an advanced tool that requires greater capability, employs a Raspberry Pi 3B as its flight computer. This allows for a wider range of science objectives and faster processing, but comes at the expense of increased code complexity. The educational payload, on the other hand, employs an Arduino UNO as the basis of its flight computer module. While the UNO is not as powerful as the Raspberry Pi, its greater simplicity, coupled with the friendly Arduino IDE coding environment, makes writing flight software more accessible to less experienced programmers.

Educational Payload Components

As an educational tool and outreach tool intended to teach students the basics of spacecraft design, the educational payload includes a variety of components designed to achieve specific educational objectives. On-board external and internal temperature sensors allow students the opportunity to interface with I^2C (internal temperature) and analog (external temperature) sensors. Meanwhile, a heater controlled digitally by the Arduino UNO flight computer introduces students to the basics of feedback control. A GPS, which interfaces over I^2C, correlates sensor data collected with altitude, and enables students to operate missions that require an on-board knowledge of altitude. Finally, a camera with video capability, digitally controlled by the Arduino UNO, encourages students to think critically about their mission design by allowing them to decide when to capture photos versus video.

In addition to the "basic" suite of sensors automatically included on the educational flight computer module, students in the AE 2790 class are required to write a proposal for adding an additional analog sensor, which they use to conduct a science mission. This sensor can be one of many analog devices, such as a light sensor, humidity sensor, pressure sensor, or accelerometer. Future concepts could even include students linking payloads with Bluetooth or WiFi to achieve mission objectives.

Software Development

Software development for the educational payload is accomplished in the Arduino IDE environment, which consists of a user-friendly code development GUI based on the C language. In this environment, students can use Arduino libraries and the built-in Arduino IDE compiler to quickly develop and test code, even with a very limited knowledge of programming. When they are ready to test code using the Arduino, students can easily deploy their code to the device over USB. During the code development process, students are encouraged to seek out answers and solve problems on their own, rather than relying on instructor assistance – a structure that would not be possible without the Arduino IDE development environment.

Concept of Operations

The Concept of Operations (ConOps) of a Balloon-CubeSat flight largely mirrors that of a CubeSat in LEO. On launch day, Missouri S&T instructors and teaching assistants prepare the balloon and payload for launch, while students perform pre-flight checks on their payloads. At this point, students will have already conducted a full "Day in the Life" test on their payload, then sealed it and passed it off to Missouri S&T staff – much the same way that a CubeSat might be passed off to a launch provider. Once the pre-flight checks are complete, students are allowed to turn on their payloads just prior to launch – the "initialization" phase.

Once the balloon is fully filled and Missouri S&T staff are ready to launch, the payloads enter the "launch" phase. After a short countdown, the balloon is released. The balloon and payloads will ascend to approximately 100,000 feet over the course of approximately 90 minutes. The balloon will then burst (due to its expansion in the lower ambient pressure approaching 100,000 feet) and a parachute deploys ensuring that they payloads land safely, typically around 45 minutes after balloon burst. During this time, each individual payload will conduct its own ConOps, which can consist simply of data col-

lection, or include multiple modes. On the ground, Missouri S&T staff use the balloon flight prediction and tracking payload radio link to follow the payloads to their landing location, then attempt a recovery. Once the payloads have landed, they are considered to be in the "end of life" phase.

BalloonSat Toolkit

In addition to the development of the BalloonCubeSat payloads, a comprehensive prediction, tracking, control and analysis software application is being developed to support the program. Currently, the program uses several resources available online and developed in-house. The BalloonSat toolkit is written in Python and LabVIEW, and the hardware acquisition is the only expenditure. The hardware and software overview of the systems is shown in the block diagram in Fig. 5. The system is broken down into the two parts: the primary payload that is attached to the flight string and the mobile ground station. The payload is an Arduino-based system that integrates various sensors, a Garmin 18x PC GPS,[10] and a Digi-XTned 900 MHz radio[11] using a custom-designed circuit board. The primary role of the system is to record in-flight GPS and sensor data while transmitting the data to the ground station at a fixed user interval real-time. The ground station is connected to the receiving Digi-Xtned 900 MHz radio[11] and a Garmin 18x USB GPS[10] via a USB interface.

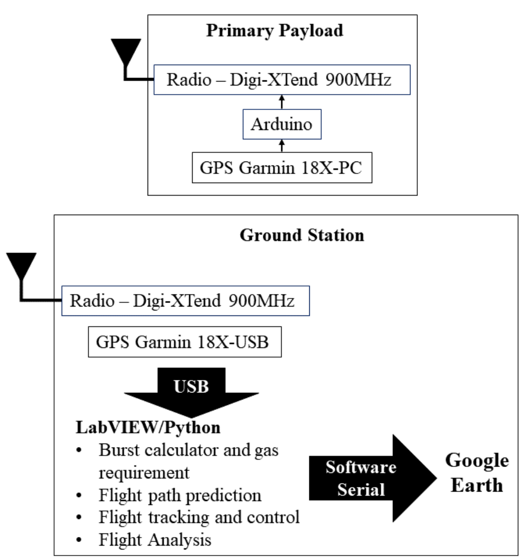

Figure 5: Hardware and Software System Block Diagrams

The BalloonSat toolkit software has five essential sections. The first two sections of the program provides balloon flight planning and predictions, the third section supports real-time flight tracking, and the final section analyzes the flight data recorded on the primary payload. The first component of the flight planning section enables users to calculate the amount of gas required, and the second part makes a flight path prediction using NOAA weather data and a prediction model based on Sobester et al.[12] The real-time tracking is accomplished by processing the data transmitted by the primary payload that is received by the mobile ground station radio. The data is parsed instantaneously, and the GPS location of the balloon is transferred to Google Earth via software serial. The current GPS location of the tracking station is also displayed in Google Earth, enabling users to visualize the relative position of the balloon and begin recovery route planning. The last section of the toolkit software takes the log file from the primary payload, parses the data and generates plots, flight analysis reports, and flight path maps. This all-in-one system is designed with a user-friendly interface and featuring a dashboard that demonstrates all aspects of the software to students, giving them a glimpse into the prediction and tracking methods used to find their payloads, as well a quickly generating data visualization plots.

EXPECTED PROGRAM OUTCOMES

The program revision to a BalloonCubeSat format has many expected outcomes in three primary areas: technical capability, educational effectiveness, and applicability as a future research platform. In terms of technical capability, the revised payload with an on-board GPS provides more a complete data set than having pressure or temperature data alone. With the GPS accuracy, data products from other sensors can be better correlated to specific regions in the atmosphere, and the complete flight path provided by the latitude and longitude data enables students to compare data collected across large regions with localized weather stations and observers. The new design's modularity also provides a an increased ability to fly a variety of experiments. A breadboarding area and standard header make it simple to integrate new sensors and other hardware, which keeps the payload flexible in terms of flying unique student envisioned and designed experiments. The standard header and payload dimensions also provide a platform to test EDU COTS CubeSat components, giving teams developing new CubeSat experience and confidence in their hardware/software in a lower risk/reduced cost launch before integrating and testing the flight unit. Finally, the new design meets its target goal of reducing the individual pay-

load mass, which enables flights with large numbers of individual payloads to continue flying to ∼100,000 feet.

The expected educational outcomes of the BalloonCubeSat program are aimed primarily at sophomore-level aerospace engineering students. These students often struggle with the decision of whether to pursue an aeronautical or astronautical-focused education/career. One of the most notable outcomes for sophomore students at Missouri S&T is that they be exposed to the basic concepts of spacecraft design (while taking a parallel course that introduces aircraft design). This outcome allows them to begin to make a better-informed choice on the nature of their senior design culminating experience, and even what specific direction to pursue as a career. They also experience the challenges of developing CubeSats in terms of generating a low SWaP payload that is capable of performing a valuable science mission. The requirement that student payloads fit within the CubeSat form factor serves as a stronger application to culminating senior design experiences (that include participation on CubeSat teams), while introducing students to all major spacecraft subsystems found in larger spacecraft as well. The modular design and ability to divide elements of the project between team members enables students to explore a depth area of their interest in satellite development while still exposing them to a variety of subsystems in aerospace engineering. This division of labor and project tasks also provides a platform to teach project and team management strategies to these rising sophomores, further preparing them for their future academic and professional careers. Finally, the fixed nature of the system critical payload components ensures some level of spacecraft success, but the flexibility for students to design their own missions and integrate their own hardware presents students with the possibility of measured failures. This possibility of a measured failure challenges students to evaluate the risk factors in their design, as well as compose tests and documentation to justify the soundness of their proposed experiment payload.

Finally, the development of the BalloonCubeSat design is expected to expand the ability of advanced research high-altitude balloon flights to test low-TRL SmallSat technologies. The design will act as a testbed for CubeSat systems, and leverages the COTS plug-and-play mentality. The power board includes 3.3 and 5 volt regulators that can be optionally populated to support common hardware specifications, and the Raspberry Pi flight computer board has a variety of interfaces to support different communication protocols. This design enables a variety of payloads to be swapped in and out to accommodate various research concepts.

RESULTS

Table 1 shows a breakdown of the overall program costs per payload. Of importance to note is that the Arduino UNO, camera, and GPS are reused (assuming they are undamaged from their previous flight) in subsequent flights and represent a one-time or periodic investment. This low baseline launch cost provides an affordable platform to implement a hands-on STEM learning experience for groups of students, while the modular payload design can accommodate more advanced projects should educators choose to add in more payload elements.

Table 1: Costs Associated with BalloonCubeSat Build

BalloonCubeSat Build and Launch Costs	
Arduino Uno	$22.00
Mini Camera	$12.50
ZOE-M8Q GPS and Antenna	$48.00
Digital Temperature Sensor	$5.95
Power, Shield, and Switch Boards	$33.00
Foam Core	$5.00
Misc. Payload Components	$20.00
Total Cost	**$146.45**

Test Results

In May 2019, extensive ground testing and a test flight were conducted with the student and research payloads to verify their performance and characterize the forces experienced during flight. Ground testing was used to verify that the power consumption of both payloads were such that the payload batteries would support operation for the duration of the flight. It was also used to confirm nominal operation of both payloads. Flight testing of the student payload allowed it to operate in its expected environment, and confirmed that no unexpected errors occurred during flight. Because the location of the balloon string was moved from the center of the payload to its edge, the acceleration experienced by the payloads was of particular interest during this flight. The research payload was therefore equipped with an accelerometer for the test flight, which was used to quantify the forces on the new payload during ascent, balloon burst, and descent.

Power consumption results are shown in Table 2,

and are well within the 1000 mA limit at which the payloads can no longer operate for a full flight. Note that, for the power consumption test, both payloads were left in the laboratory "flatsat" form, and were fully equipped with all sensors used for flight.

Table 2: Payload Power Consumption

	Heater Off (mA)	Heater On (mA)
Student Payload	150	500
Research Payload	200	N/A

Prior to flight, the masses of both payloads were measured and compared to the 700 g mass of the previous payload configuration. The results show a large mass savings, and are presented in Table 3.

Table 3: Payload Mass Comparison

	Mass (g)	% Savings
Student Payload	408	~41
Research Payload	430	N/A

The test flight, conducted from the Missouri S&T campus, lasted approximately 140 minutes, with an approximate 95 minute ascent and a 45 minute descent. The flight demonstrated successful operation of both payloads, with the exception of a GPS malfunction that caused data to be recorded for only a portion of the flight. Fig. 6 shows internal and external temperature data from the student payload. It also clearly demonstrates that the payload heater was able to maintain its internal temperature at its set target of 10 °C on ascent, but was not able to maintain the same temperature on descent.

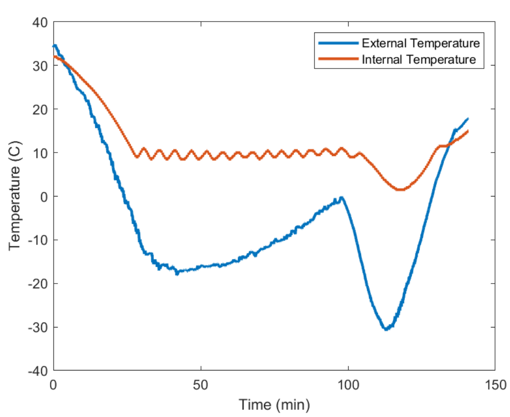

Figure 6: Internal and External Temperature

On the research payload, acceleration data were collected along each axis at a rate of 10 Hz for the duration of the flight. Figs. 7-9 show this acceleration. Note that the accelerometer used is unable to read acceleration greater in magnitude than 16 g and, therefore, was unable to fully capture the acceleration experienced during balloon burst.

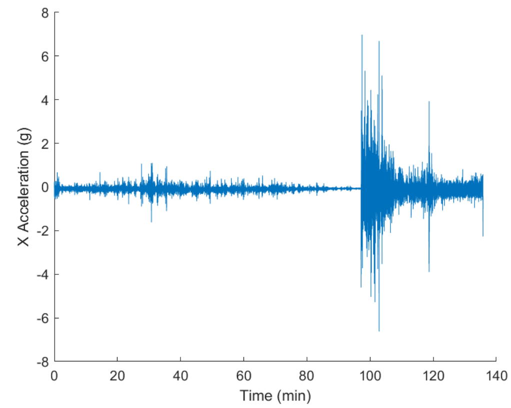

Figure 7: X (In-Plane) Acceleration

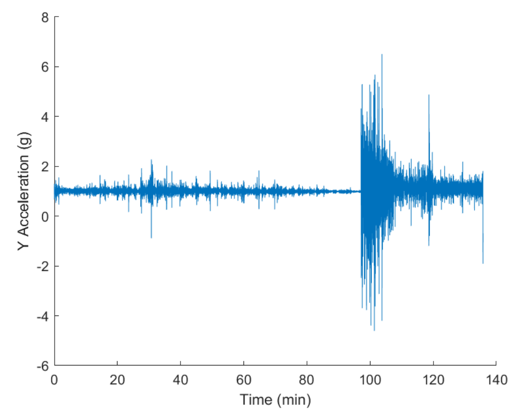

Figure 8: Y (Vertical) Acceleration

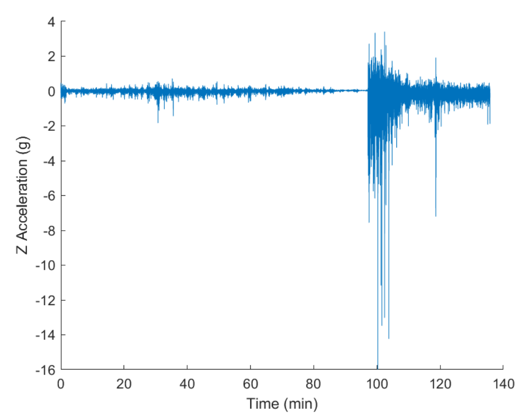

Figure 9: Z (In-Plane) Acceleration

In the figures, several distinct spikes are visible. The first, at approximately 95 minutes, captured the balloon burst and subsequent free-fall prior to full parachute deployment. The second, at approximately 120 minutes, captured an event

following burst – likely the parachute reaching full deployment. The third, at approximately 140 minutes, captured the payload touching down on the ground. While the acceleration magnitude experienced by the payloads during burst is large, it is expected, and consistent with data from previous launches. This result, coupled with the observation that neither payload showed visible damage after the flight, indicates that the new design is structurally sound and does not require a design update prior to future flights.

In addition to the test flight of the redesigned payload, sophomore aerospace students were also surveyed at the beginning and end of the Spring 2019 semester to gauge the impact of the newly required course. Students were surveyed in the Introduction to Spacecraft Design (AE 2790) course and the Introduction to Aircraft Design (AE 2780) course. Of the current aerospace sophomores, 55 surveyed students took AE 2790 and 16 did not. Exposure to the AE 2790 course material appeared to to increase student participation in hands-on design projects on campus related to spacecraft design. Of the 55 students enrolled in both AE 2780 and AE 2790 during this semester, nine joined a spacecraft-related design team on campus while only one student enrolled in AE 2780 joined a spacecraft-related design team on campus.
Preliminary data suggest that exposure to both aircraft and spacecraft design courses during sophomore year helped students choose focus areas for their future design coursework and career direction. At the end of the semester surveys, only 20% of students completing both design courses (2780/2790) responded that they were undecided about which senior design course (aircraft of spacecraft design) they will take compared to 33% of students completing only AE 2780. When asked about career plans, 5.4% of students completing both design courses (AE 2780/2790) responded that they were undecided about the field in which they plan to seek employment or graduate school opportunities compared to 19% of students completing only AE 2780. Research is ongoing to track these students as they progress through the aerospace engineering program and provide additional insight into the impact of AE 2790.

CONCLUSIONS

The new BalloonCubeSat payload is a sustainable solution to increase the technical capability, educational effectiveness, and research applications for high altitude balloon programs as a complimentary element to small satellite design and research programs. The payload design mimicking CubeSat standard footprint introduces students to the challenges of small spacecraft design and integration, while the accompanying course curriculum introduces students to space systems engineering applicable to large and small spacecraft. The new design includes a GPS receiver and internal and external temperature sensors, with connections available to include additional sensors. The results of the first test of this payload shows full system functionality, with plenty margin in mass, volume, and power to add additional sensors if needed. The individual payload mass was sufficiently reduced to continue flying an increased number of payloads without needing a larger high altitude balloon.

FUTURE WORK

In the future, this project will be expanded and refined to further engage students in STEM learning experiences serve as a valuable program to better prepare students for careers related to spaceflight. In future summer camps and semester courses, additional pedagogical data will be collected to gauge student comprehension of the subject matter as well as how the program helps to develop critical thinking, project management, and team dynamic skills. Additionally, with the research payload fully tested, flights can begin in support of advanced research topics. One topic of interest is to evaluate vision processing algorithm performance for spacecraft operating in close-proximity operations. These operations can be simulated using spacecraft payloads attached to the flight string in known configurations, and the algorithm performance can be evaluated in a dynamic environment with variable viewing angles and lighting conditions. Finally, it is hoped that the payloads can be offered as kits to STEM educators who work with students in their home locations to develop payloads that are launched from the Missouri S&T campus.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the AFRL University Nanosatellite Program for providing the original inspiration for developing the high-altitude balloon program described in this paper. The NASA-Missouri Space Grant Consortium is also gratefully acknowledged for their financial support.

REFERENCES

1. "Reaching New Heights Through Science and STEM." `https://stratostar.net/`. Accessed: 2019-06-7.

2. “Taking You and Your Payload to Near-Space.” https://launchwithus.org/. Accessed: 2019-06-7.
3. “GOMSPACE 1U and 2U CubeSat Platforms.” https://gomspace.com/1u-2u-platform.aspx. Accessed: 2019-06-7.
4. “Clyde Space 1U Platform.” https://www.clyde.space/products/70-1u-platform. Accessed: 2019-06-7.
5. R. Twiggs, A. Zucherman, E. Bujold, N. Counts, christopher Colman, J. L. Garcia, A. Diddle, and P. Zhirkina, “The ThinSat Program: Flight Opportunities for Education, Research, and Industry,” *Proceedings of the AIAA/USU Conference on Small Satellites*, 2018.
6. M. Swartwout, “Reliving 24 Years in the Next 12 Minutes: A Statistical and Personal History of University-Class Satellites,” *Proceedings of the AIAA/USU Conference on Small Satellites*, 2018.
7. M. Yamazaki and T. Zengo, “HEPTA-Sat Training Program: International Knowledge Transfer Using Hands-On Type CubeSat Education,” *Proceedings of the AIAA/USU Conference on Small Satellites*, 2018.
8. “Launchbox.” http://www.launchboxspace.com/store/mission-2-edge-of-space-primary-schools. Accessed: 2019-06-11.
9. “Educational CubeSat Missions Using High Altitude Balloons.” https://digitalcommons.usu.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=3275&context=smallsat. Accessed: 2019-06-11.
10. “GPS 18x OEM Garmin Ltd..” https://buy.garmin.com/en-US/US/p/27594. Accessed: 2019-06-6.
11. “Digi XTend 900 MHz Digi International Inc.” https://www.digi.com/products/embedded-systems/rf-modules/sub-1-ghz-modules/xtend-module. Accessed: 2019-06-6.
12. A. Sóbester, H. Czerski, and I. Castro, “High Altitude Gas Balloon Trajectory Prediction: A Monte Carlo Model,” *AIAA Journal*, vol. 52, no. 4, pp. 832–842, 2014.