Flying "Mock" CubeSats on Stratospheric Balloon Flights: An Update about "Mock P-PODs" and the 3U "MOC-SOC"

Paul Wehling[1]
University of Minnesota, Twin Cities, Minneapolis, Minnesota, 55455

Andrew Van Gerpen[2]
University of Minnesota, Twin Cities, Minneapolis, Minnesota, 55455

James Flaten[3]
Minnesota Space Grant Consortium, Minneapolis, Minnesota, 55455

1) Abstract

CubeSats are miniature satellites measuring 10 cm x 10 cm x 10cm, 20cm, or 30 cm (1U, 2U, or 3U, respectively) that are often launched to orbit alongside larger payloads and deployed once in orbit from an ejection device known as a "P-POD" or from launchers onboard the International Space Station. At AHAC 2019 we discussed how we help train both stratospheric ballooning students and also CubeSat development team members by challenging them to design and build functional, low-cost, non-space-rated ("mock") CubeSat-shaped payloads then fly them, inside a "mock P-POD", into the stratosphere on weather balloon flights. Mock CubeSats flown have varied widely in complexity and build, demonstrating the usefulness of the platform, from basic shells filled with independent commercial-off-the-shelf sensors and equipment to custom-built platforms with ground telemetry links and "smart" sensor-driven software. The largest and most technically complex of our mock CubeSats to date, "MOC-SOC", along with our mock P-POD have undergone significant developments since our 2019 presentation. These changes have demonstrated the advantages of a stratospheric mock CubeSat program to students training and payload development, and also clarified some of the limits of replicating aspects of genuinely-space-bound payloads in the atmosphere. Results from three balloon flights carrying MOC-SOC in the summer of 2020 will be discussed.

2) Introduction

At AHAC 2019 we discussed building and experimentation with tiny, low-cost satellites in a "CubeSat" form factor which were then flown on stratospheric ballooning flights. [2] In the past year development progress has continued on our mock-CubeSat carrier/launcher (AKA mock P-POD - hereafter merely called the P-POD), as well as on the most-complex of our mock CubeSat payloads, MOC-SOC.

At the time of presentation last year, MOC-SOC (and all other mock CubeSats) were mounted in the P-POD inside foam-core "cases" which protected the payloads from damage after deployment and accommodated fairly-standard ballooning rigging from which the mock CubeSat(s) would dangle separately beneath the P-POD after a mid-ascent "deployment." MOC-SOC was initially held within P-POD by means of a lid/floor strapped to the bottom of the P-POD by a pair of taut rigging lines that wrapped around the entirety of the P-POD body. When the lines were released, the lid/floor, with MOC-SOC riding on top of it, would slide down rigging lines beneath P-POD until reaching a stop in the lines extending to the next payload below P-POD. Hence there was always at least one payload below the P-POD to keep those lines taut during ascent. That lower payload typically contained an upward-looking camera, at least, to document the deployment of the CubeSat(s) from below. In the case of MOC-SOC, after a pause of roughly five minutes after deployment from the P-POD, MOC-SOC would extend deployable "solar" panels from its sides much like many real CubeSats.

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[1] Undergraduate student, Department of Aerospace Engineering and Mechanics.
[2] Undergraduate student, Department of Aerospace Engineering and Mechanics.
[3] Associate Director, Minnesota Space Grant Consortium

The P-POD carried a minimal sensor bank and deployed the CubeSat(s) based on a timer, whereas MOC-SOC maintained radio communication with both P-POD, using a short-range XBee3 radio module, and a ground station, using a longer-range FreeWave radio. MOC-SOC took and recorded continuous data from a sensor array including measurements of electrical flow from the solar panels and also from its main instrument, an Aware RM-60 Geiger counter.

During AHAC 2019 we discussed a partially-successful flight which showed the capabilities of MOC-SOC's primary instrument suite but experienced difficulties with both solar panel deployment and radio connectivity to the ground station. At the end of the section in Ref. [2] about MOC-SOC we stated that "we intend to keep working on troubleshooting the design and hope to re-fly MOC-SOC in the future and successfully exercise more of its functionality."

3) Continued Development of MOC-SOC

Some of the adjustments made to the MOC-SOC payload, including a complete flight code overhaul, are of limited interest to the discussion of CubeSat ballooning at large and so will be passed over here. Other changes and lessons learned, however, may be of interest to others considering trying "CubeSat ballooning." Some of the development that MOC-SOC has undergone has been in an effort to make it more resilient to operating in an environment with full gravity, as opposed to the free-fall conditions on orbit, which necessitated deviating from the original mission concept of replicating CubeSats as closely as possible.

Firstly, the deployment system for both the solar panels and for the mock CubeSat itself underwent significant modification. The foam-core "cases" were difficult to work with and obstructed access to the payload after rigging. However it was relatively easy to integrate tubing to accept rigging lines directly onto MOC-SOC's body.

Not unexpectedly, MOC-SOC often experiences heavy shocks on landing at the end of a ballooning mission, especially given its relatively-hard construction compared to some ballooning payloads. This rough environment has necessitated that MOC-SOC be built to higher structural standards than regular payloads, in some ways coming internally closer to its space-faring inspiration. All electronics have been firmly mounted to shields and then screwed to the payload hull, and all other electrical and signal connections are now made through proper connectors. We also found that making the wall to which the electronics were fastened removable even after rigging allowed much better access, rigidity, and usable internal volume (see Figures 1 and 2) than comparable designs involving a removable "shelf" such as the designs briefly discussed in the AHAC 2019 presentation. The solar panels, while being originally connected to the body with segments of tape-measure strips (inspired by the same system on board the University of Minnesota - Twin Cities' first spacefaring CubeSat, SOCRATES), had to be switched out to spring loaded hinges after loss of panels during descent/landing on ballooning missions.

Radio connection to the ground station has continued to be an issue, although some progress has been made in the past year. One of the defining features of the multi-U CubeSat layout is that "long" items, such as antennas, often can only be internally mounted in one direction - parallel to the long axis of the CubeSat. Since we fly mock-CubeSats vertically, making a radio connection can be a difficult proposition when the ground station is located basically underneath the stack. Although we have found the onboard Freewave MM-2 radios outperform our usual RFD900 telemetry radios during ground tests, on our flights radio connection with MOC-SOC has been problematic when the balloon is above about 50,000 feet altitude. In some ways this has been beneficial to the goal of challenging students, requiring more advanced telemetry protocols that check for ground connection and re-transmit data when need be, mimicking real CubeSat solutions. It has been considered that mounting antennas under the solar panels (so that they deploy perpendicular to the ground) might increase the quality of in-flight radio communications with the ground station, but this has not yet been attempted.

Reliable deployment of MOC-SOC's solar panels, which was elusive at first, has been achieved using a set of redundant deployment criterion including (a) short-range radio command exchanges with P-POD, (b) a hard timer, (c) altitude triggers, and (d) GPS fences. Due to a robust radio command system, all of these criteria can be modified or disabled in-flight by uplink from the ground station, which has proved useful multiple times.

To summarize, in the past year updates to MOC-SOC stepped somewhat farther away from it being a low-cost replica of an outer-space CubeSat in order to function more reliably as a ballooning payload. Durability, especially after deployment, has become a main focus of recent development. However MOC-SOC and other mock CubeSats still retain their usefulness as educational training projects as discussed in the AHAC 2019 presentation because they require students to design more carefully and rigorously than might be needed for a more-traditional ballooning payloads, both in regards to the physical structure and the operating software.

4) Continued Development of the Mock P-POD

The P-POD changed in two major ways since the AHAC 2019 presentation. First, its electronics were replaced by a PTERODACTYL sensors board (see Andrew Van Gerpen's 2020 AHAC oral presentation about that modular hardware [1]). Also, the deployment system was significantly upgraded with an eye to avoid line tangling below the P-POD on accent prior to, and after, CubeSat deployment. Since the electronics changes are largely covered in Ref. [1], they will be skipped over here. The latter modifications, however, deserves a brief discussion.

In early flights (prior to AHAC 2019), the P-POD had issues with tangling of the rigging lines below the box during ascent which would sometimes impede, or even prevent, successful CubeSat deployment down the strings below the P-POD. Modifications were designed, ground tested, and flight tested to prevent this. The bottom cover of P-POD, originally a lid/floor that would descend with the bottom-most deployed CubeSat, has been replaced with a pair of doors which, when released, spring open laterally allowing the CubeSat(s) to pass them as they slide down the rigging lines toward the payload below. The most substantial part of the ultimate design change was the adoption of "rigging spacers" beneath P-POD (see f\Figures 3 through 5). These styrofoam frames hang by a single, centerline rigging line and are spaced about six inches vertically. This line is tied to the bottom of the lowest mock CubeSat. The four main rigging lines are allowed to move freely through plastic tubing at each corner of each rigging spacer. The rigging spacers are designed such that any rotation of the four main rigging lines between P-POD and the payload below will significantly decrease the vertical separation between the two payloads, and so the bottom box's weight will generate a restoring moment in the assembly. In flights, this system has been found to virtually eliminate line tangling (or even prevent significant rotation) along the stretch of rigging line they have been employed on. (Aside: It might be possible to use this approach and incorporate rigging spacers between payloads on any balloon flights, not just those involving mock CubeSats, to limit relative rotation of payloads and tangling of parallel rigging lines.) Deployment of P-POD's CubeSat payload(s) is unhampered by the "spacers" which just collapse together until touching once they lose tension along the middle line as the bottom mock CubeSat descends along the lines. The only major concern with rigging spaces is that they tend to be destroyed during the rougher environment of descent if they have not already been collapsed (i.e. if P-POD fails to deploy its cubes for any reason). Such "rigging spacers" could presumably be made of tougher material than styrofoam such as laser-cut mdf or 3D printed plastic to provide better resilience to post-burst chaos.

To summarize, the mock P-POD design also had to move somewhat farther away from its outer space counterparts in order to be more practical and reliable in balloon flights. The "rigging spacers" are, both for P-POD and for other applications, a reliable, low-cost/low-weight method of reducing line tangling and relative rotation between payloads.

5) Flights of the MOC-SOC and P-POD System During the Summer of 2020

The P-POD, carrying MOC-SOC, flew three times during the summer of 2020. The first and third flights saw MOC-SOC perform largely successfully, in the latter case exactly as designed, but the P-POD failed to deploy MOC-SOC at the appropriate time during the ascent. The second flight saw the successful deployment of MOC-SOC from the P-POD, but a failure to deploy panels by MOC-SOC. Despite these failures, the summer launches, especially the last one, can be largely considered successful in that they demonstrated the utility of the new radio protocols and anti-tangle devices on the lines below the P-POD. The flights proved the need for, and later the resilience of, a significantly tougher build for MOC-SOC. In the final flight both the payload electronically worked completely as intended and the P-POD was only prevented from deploying MOC-SOC successfully by a misplaced zip-tie.

Although data from the internal sensors is not the main object of the MOC-SOC development project, since it is intended as more of a technology demonstrator than useful scientific endeavor, the internal Geiger counter collected data on all three flights that agrees with expected values for atmospheric cosmic radiation. Because of the unfortunate deployment failures the solar panel data, which was an important dataset that we were hoping to acquire, remains elusive. On the other hand, we have learned from onboard temperature sensors that the P-POD shell is an effective thermal insulator, keeping MOC-SOC at or above regular ballooning payload temperatures prior to ejection. As expected, after ejection (above the tropopause) the internal temperature of the intentionally-porous MOC-SOC quickly reaches the ambient atmosphere temperature, despite the use of chemical hand warmers to try to provide heating of batteries.

6) Conclusion

Flying mock-CubeSats has continued to show its worth as a challenging task for ballooning and satellite-building students alike. This task forces the application of creative and resilient thinking and design to solve volume-constrained physical and electronic problems.

That being said, we have also found in the past year that some of the restrictions forced by flying on stratospheric balloon missions instead of in outer space have necessitated some turning away from a concept originally intended to replicate real CubeSats as closely as possible, and this new category of near-space vehicle has come to adopt its own rules and challenges independent of both traditional CubeSats and traditional ballooning payloads.

Appendix

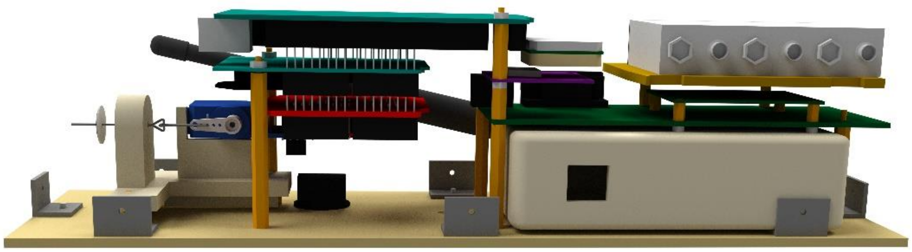

Figure 1: Rendering of MOC-SOC's major internal elements, mounted on a removable wall.

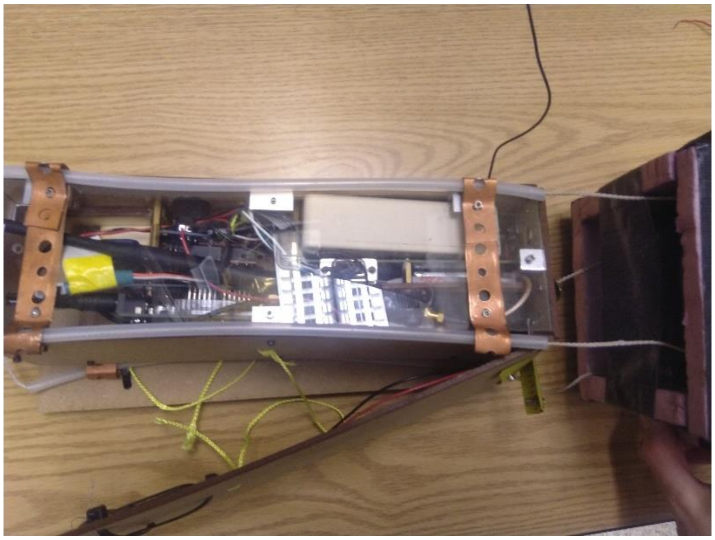

Figure 2: View of a slightly older version of MOC-SOC showing its clear wall for troubleshooting and display.

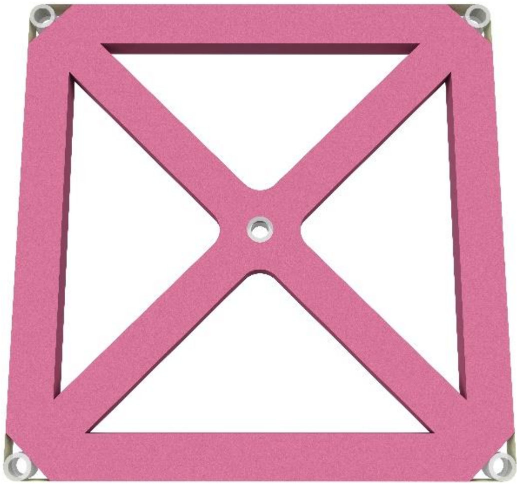

Figure 3: Close-up of a rigging spacer element, as described in Section 4.

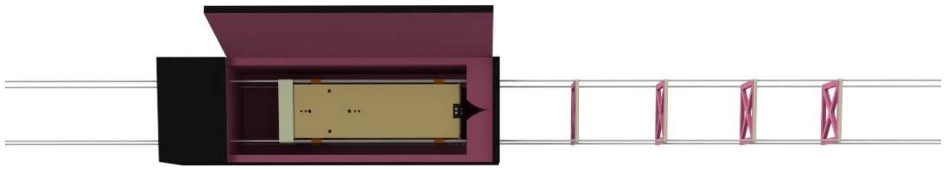

Figure 4: Rendering of the P-POD during ascent, with rigging spacers acting below.

Figure 5: Insertion of MOC-SOC into P-POD during a summer launch, showing the rigging spacers on the lines below the P-POD.

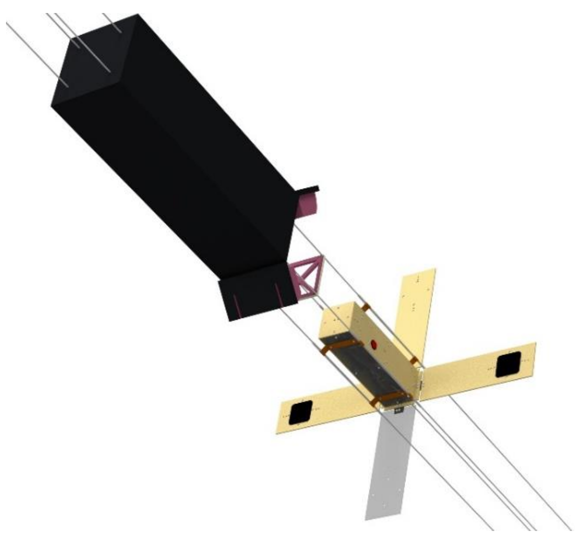

Figure 6: Rendering of MOC-SOC after deployment. Note one rigging spacer in view above MOC-SOC.

Acknowledgments

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References

[1] Van Gerpen A. and Flaten, J., "Payload To Enable Recording Of Data And Communication Telemetry Y(While) Lofted (PTERODACTYL), with Stratospheric Ballooning Applications", *Academic High Altitude Conference 2020* (oral presentation).

[2] Flaten J. & Bartlett J. & Krieg E. & Lenz E. & Bowers R., "Flying "Mock CubeSats" on Stratospheric Balloon Missions", *Academic High Altitude Conference* 2019, Iowa State University, Ames, Iowa, 2020.