

2nd Eye in the Sky

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Abstract

Student designed high altitude balloon payloads often encounter unexpected challenges during development and flight. While many teams anticipate potential problems and develop contingency plans, unforeseen design flaws can still result in partial or complete payload failure. At Pikes Peak State College, a previous team developed a camera payload using a small onboard micro controller system, an action camera, and a custom fabricated enclosure. That payload successfully captured images during flight and later served as a backup design for subsequent teams. When the design was reused during a later launch attempt, several structural and operational limitations became apparent, revealing weaknesses in the original system. The goal of this project is to redesign this payload to create a reliable imaging system dedicated to capturing views of Earth from the environment of a high-altitude balloon flight. The redesigned payload incorporates two independent recording systems. An external action camera captures wide-field visual footage of the surrounding environment while an internal camera system connected to a small onboard computer records additional imagery from within the payload enclosure. By integrating multiple recording methods, the payload aims to improve reliability and reduce the risk of data loss during flight. The redesign process focuses on several major goals. The first is to establish a more structurally stable platform for mounting an external recording device using components produced through additive manufacturing. The second is to improve the thermal stability of the internal environment of the payload. Earlier designs did not adequately consider temperature fluctuations and allowed little space for insulation or thermal management. Preliminary ground testing of the redesigned structure and thermal layout is intended to verify the durability of the enclosure and the stability of the internal environment prior to flight. Finally, the design process also emphasizes ease of assembly so that the payload can be reliably constructed, modified, and reused by future student teams. The long-term objective of this work is to establish a dependable payload that can be launched repeatedly by students to document Earth from high altitude and support future educational and research activities involving near space balloon missions. This project also aims to expand understanding of how additively manufactured components perform in low atmosphere environments and to provide a design framework that future student teams can build upon.

1 Introduction

Pikes Peak State College has a relatively short but focused history in the development of visual imaging payloads. The first payload designed for this purpose was launched on April 2, 2022, exactly four years prior to the launch of this payload [1]. The original payload, designed by Jeremy Lee, was intended as a backup to a primary design but ultimately proved successful in flight.

During the 2022 mission, a twin set of payloads was launched on the same flight string. One payload contained a GoPro Hero 3 Pro action camera, while the second incorporated a 360-degree camera that has not been definitively identified. Video footage from this launch, currently available on YouTube, demonstrates the overall success of the payload, capturing key events such as liftoff, ascent, and balloon burst.

This design was later reused as a final payload and was presented as part of the Colorado Space Grant Research Symposium 2025 [2]. However, during this subsequent launch, several failures occurred that were not observed in the original flight and video. Unlike the 2022 flight, only the GoPro camera was utilized. Upon launch, the camera shifted from its intended position, resulting in footage primarily showing the flight string and the payload below it. Additionally, the camera battery died before the balloon burst, limiting the data set as well.

These issues pointed out a factor key to the success of the 2022 launch. The inclusion of a secondary 360-degree camera minimized any potential for failure due to its wide angle. Without this design choice, the impact of design flaws became significantly more pronounced.

These launches serve as the main inspiration for this project, providing a baseline to work off of, showing the priorities of this project, and providing a standard that the new design aimed to surpass.

2 Background and Previous Design

2.1 Original Payload System

The original payload was designed to accomplish two objectives: capture visual data during flight and collect atmospheric data throughout. The internal compartment housed an Arduino Uno with a sensor shield kit provided by the University of Colorado Boulder. This system included an accelerometer, humidity sensor, pressure sensor, and two temperature sensors.

The use of this pre-configured sensor package allowed for rapid integration and reliable data collection, making it well suited for use in a backup payload. Externally, the payload utilized a standard GoPro mounting system consisting of a clamped multi-slotted bracket secured by a bolt. The original payload utilized an externally mounted camera, as shown in Figure 1, and compact enclosure design. While this mounting system is widely used and effective in most applications, it is sensitive to manufacturing tolerances and can be influenced by strong forces.



Figure 1: 2022 payload design used as the baseline for the redesign

The enclosure and structural components were fabricated using additive manufacturing (3D printing). This approach provided an easy manufacturing approach and material choices, enabling rapid production. Acrylonitrile butadiene styrene (ABS) was selected as the primary material due to its favorable mechanical properties and improved performance at low temperatures [3].

The enclosure was designed to complement additive manufacturing, being able to be printed quickly, easily, and with minimal processing afterward. This manufacturability, combined with twin payloads, resulted in a successful flight. The resulting footage has since been used as an educational resource at Pikes Peak State College to support student engagement with the CU Boulder payload kits.

2.2 Identified Limitations

With the payload developed under a tight deadline, several failure points were not identified until the 2025 launch. The most significant issue was associated with the GoPro mounting system. Tolerance issues were discovered with the included mount, leaving just enough room for the launch to shift the camera downward.

This issue was likely not observed in the original implementation due to print quality issues. Earlier prints showed signs of over-extrusion, which may have unintentionally fixed any tolerance issues in the mounting system. Improvements in additive manufacturing reduced these imperfections, revealing the tolerance issue and allowing relative motion between components.

The internal structure provided no accommodation for thermal insulation of the onboard micro-

controller. Typical high-altitude balloon payloads, including the CU boulder kits, incorporate insulating materials, such as foam, to retain heat produced by any on board components and computers. The absence of insulation increased the risk of temperature-related failures.

The enclosure design also limited accessibility to internal components, making assembly difficult. This reduced the practicality of the system for reuse by future teams.

Finally, the payload design relied on the use of two independent payloads to cover for any failures during the flight. This approach depends on external redundancy rather than redundant components in a single system. As a result, the failure of a single payload significantly reduced the overall effectiveness of the mission.

These limitations outline issues with the structural design, thermal management, and system-level redundancy, providing clear guidelines for the redesign.

3 Design Requirements

The design requirements for the redesigned payload were compiled from the successful aspects of the original system and the limitations identified during the subsequent flight.

3.1 Functional Requirements

The redesigned payload was required to prioritize reusability and reproducibility. The system was designed to make use of readily available manufacturing methods, making complete assembly performable by future student teams.

To compete the use as a backup system, the payload was required to be intuitive to assemble and operate, allowing for easy production in the event of primary payload setback. The design emphasized ease of use, ensuring that the payload could be reproduced with minimal effort.

The payload was also required to provide continuous visual recording throughout the flight and to incorporate redundancy in imaging systems to mitigate the risk of data loss. The camera mounting system was required to maintain a fixed orientation under expected launch and ascent conditions.

3.2 Environmental and Design Constraints

The payload was required to operate under the environmental conditions expected with high-altitude balloon flights, reaching altitudes of approximately 100,000 ft (30 km). At these altitudes, temperatures can decrease to below -80°C [4]. As a result, the system was required to incorporate passive thermal management to retain internally generated heat and maintain components within their operational temperatures.

The payload was also required to withstand mechanical stresses encountered during launch and ascent.

In addition to environmental constraints, institutional requirements defined by the Colorado Space Grant Consortium imposed further design limitations. The payload mass was limited to 600 grams, requiring careful consideration of material selection and structural efficiency. Furthermore, the payload was required to interface with the flight string in a manner that would not interfere with adjacent payloads or compromise flight stability.

3.3 Design Priorities

Several key design priorities were identified as a result of these limitations. The primary priority was structural reliability, ensuring that all components, particularly the external camera mount, maintained their intended position throughout the duration of the flight.

The second priority was thermal stability, with an emphasis on retaining internally generated heat to protect electronic components from the low-temperature conditions encountered at high altitude.

The third priority was system-level redundancy. The payload was designed to incorporate multiple independent recording systems to reduce the risk of complete data loss in the event of a single component failure.

Finally, manufacturability and re-usability were prioritized to ensure that the payload could be easily fabricated, assembled, and used by future student teams.

These priorities guided design decisions made during the process.

4 Redesigned Payload System

With all the requirements outlined above, This new payload accomplishes the design goals in the following ways.

4.1 Original intent

When creating the body of the payload, the intent was to allow the camera to be held in place with a screw mounted box that would be screwed into the payload and prevent the camera from shifting while still recording footage. An on-board microcomputer would be mounted on the other side of the payload below the camera to allow recording from different angles and keep the payload balanced.

4.2 Structural Design

The final design utilizes a fully enclosed box structure to protect and contain all internal components. Mounting points were incorporated to accept hexagonal standoffs provided with the electronic components, improving rigidity and allowing for repeatable assembly. Opposing these mounting locations, countersunk screw features secure components directly to the enclosure walls, reducing the likelihood of loosening during flight.

Internal ribs were added to increase overall structural stiffness and reduce deformation under load. This reinforcement improves the reliability of internal mounting features and helps maintain alignment of sensitive components throughout ascent.

The external action camera is mounted within the lid to prevent lateral movement during flight. This was achieved by extruding the camera housing directly from the lid. The camera is angled at 20 degrees from vertical to ensure that the field of view captures the Earth during ascent, rather than pointing into empty sky. In all of these improvements, room was allowed so that four of the sides in the payload could account for foam insulation used for the CU boulder kit payloads. A SolidWorks render of the assembled structure can be found in Figure 2. Technical drawings for all components can be found in the appendix.

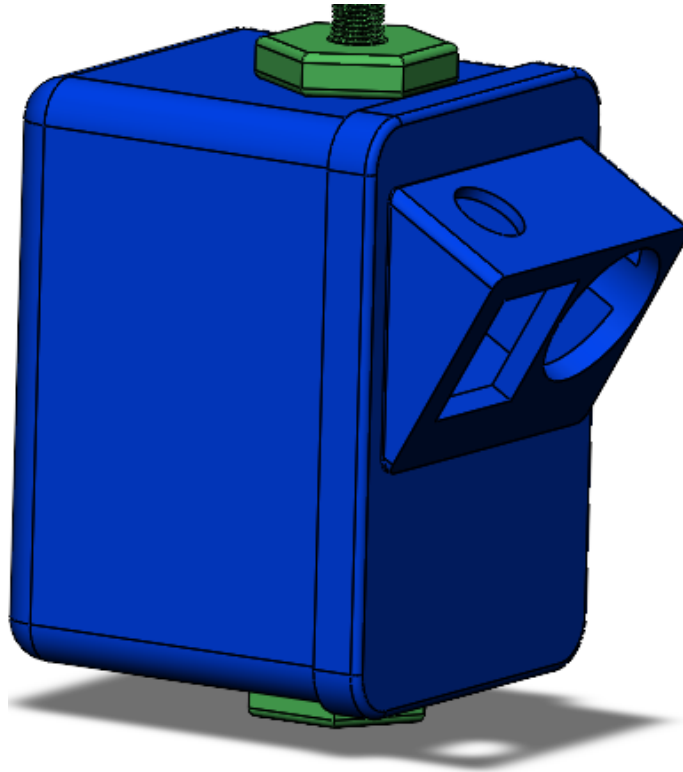


Figure 2: SolidWorks render of the redesigned payload structure

The final material selected for the structure was acrylonitrile-styrene-acrylate (ASA). This material retains key properties of acrylonitrile butadiene styrene (ABS), including temperature resistance and slight flexibility, while offering improved resistance to ultraviolet (UV) exposure[5]. The increased UV resistance was the primary factor for the material choice.

4.3 Electronics and Power System

The redesigned payload internals prioritized visual data collection over atmospheric sensing. All on board internals support this goal.

The primary imaging system utilized a DJI Action 6 camera, selected for its reliability, compact form factor, and natural cold resistance. The camera offers extended battery life and features designed for cold environments [6], this camera was an easy choice for the payload to be designed around and to be used for the independent recording system..

A Raspberry Pi 4B was selected as the primary onboard computer to enable higher processing capability and compatibility with an additional camera system. An Arducam 64 megapixel camera module was used as a secondary imaging system. This configuration allowed continuous visual recording from multiple sources throughout the flight. All this is powered by a battery hat that runs on two Lithium Ion cell batteries.

4.4 Payload Suspension Interface

This component was developed as a standardized interface for securing the payload to the flight string and has been reused across multiple payload iterations. The original purpose of this design

was to eliminate the need for improvised stabilization methods, such as paperclips, by introducing a dedicated mechanical fastening system.

The design utilizes a nut-and-bolt configuration to provide a secure and repeatable attachment point. The bolt functions as the primary load-bearing element, passing through the payload structure to anchor the system. The bolt also served as the tube, passing through the structure and giving interfacing faces for knots tied in the flight string. A threaded interface at the opposite end allows a nut to secure the assembly in place, ensuring stable connection to the flight string.

Both components were fabricated using additive manufacturing, enabling rapid production and consistent integration into multiple payload designs. This approach improved repeatability and reduced variability in the suspension system across different builds.

5 Manufacturing and Assembly

Multiple prototype iterations were required to fully refine and fabricate the final design. All components were prepared using OrcaSlicer and manufactured on a Bambu X1E 3D printer.

The development process included several test prints shown in Figure 3, focused on component interfacing, particularly the fit and alignment of electronic components within the enclosure. The final enclosure required four complete print iterations for acceptable performance.

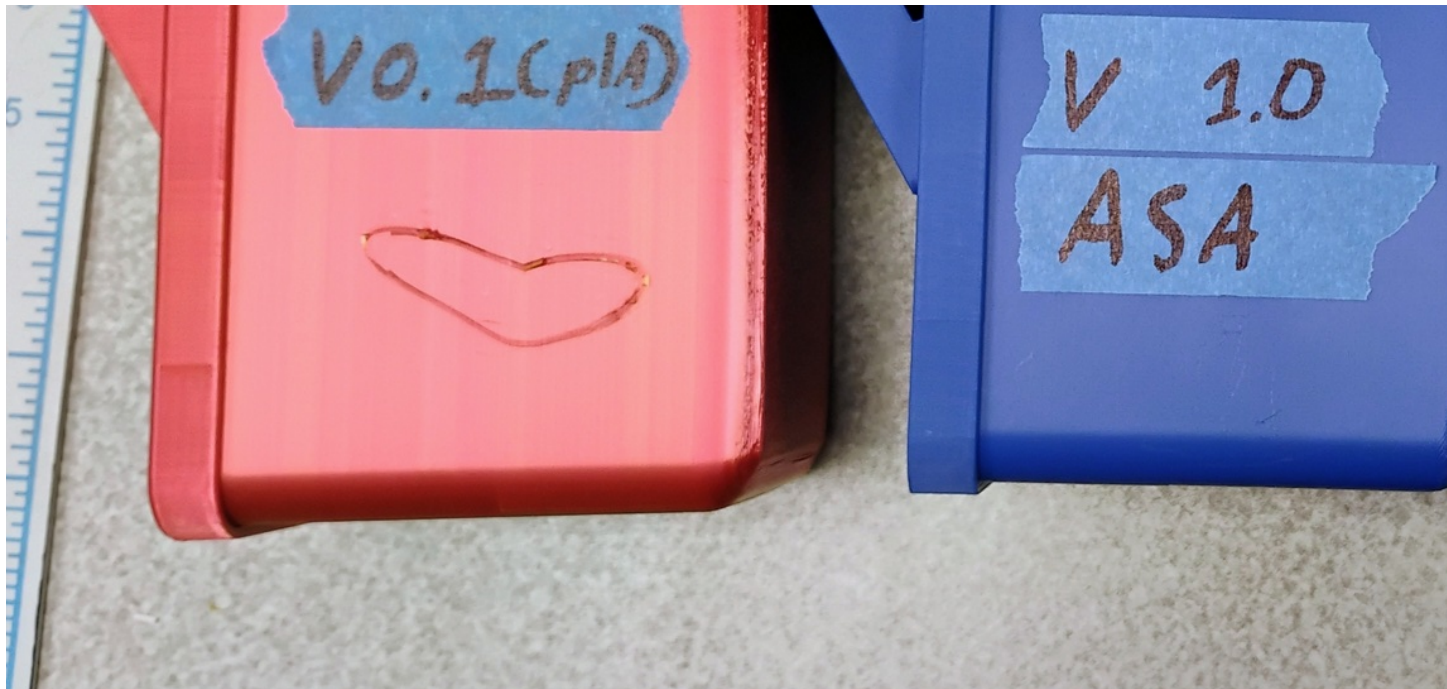


Figure 3: Prototype prints used in the production of the final payload

All test and final components were printed using four wall perimeters and 30% infill. Support structures were used for overhanging features, particularly in the lid geometry. The additive manufacturing was the longest portion of the process.

Software implementation on the Raspberry Pi was comparatively easy. The system was configured using a startup script to automate recording upon boot. The script initiates video capture, records for a fixed duration of 30 minutes, saves the output in MP4 format, and then restarts the

recording loop. This approach ensures that in the event of power loss, only a limited segment of footage is lost rather than the entire recording session.

The final product produced weighed 542 grams, 58 grams below the weight limit.

6 Testing and Validation

In order to meet flight approval requirements, the payload was subjected to a series of standardized tests. These tests included a whip test, drop test, stair-pitch test, and freeze test [4].

6.1 Ground Testing

The whip test was conducted to simulate forces experienced by the payload following balloon burst. The payload was attached to a length of para-cord and swung to induce high lateral forces. The structure and internal components remained secure, with no observable damage or component displacement.

The drop test evaluated the payload's ability to withstand impact during landing. The payload was dropped from an approximate height of 20 ft using a stairwell. No structural damage or component failure was observed following impact.

The stair-pitch test was performed to simulate ground dragging conditions after landing. The payload was rolled down the stairs, introducing repeated impacts and rotational forces. The structure remained intact with no sustained damage.

The freeze test assessed the payload's performance under low-temperature. The payload was placed in a -60°C freezer for a duration of two hours. Both the action camera and the Raspberry Pi system operated continuously throughout the test period, demonstrating adequate thermal resilience.

All tests were successfully completed, and no structural or functional failures were observed. The payload met all required criteria and was approved for flight.

6.2 Flight Day

The redesigned payload was launched on April 2, 2026, from Deer Trail Elementary aboard EOSS 393. The balloon reached a maximum altitude of 97,827 ft above sea level, with a total flight duration of 2 hours and 35 minutes [7]. The strung payload can be found in Figure 4. Additional images from the flight and recovery are provided in Appendix A..

The payload was successfully recovered intact, with no observable structural damage. Upon retrieval, the external action camera was still actively recording, indicating continuous operation throughout the flight.

7 Discussion

The redesigned payload achieved partial success based on the performance of its primary and secondary systems. The external action camera operated as intended, capturing the full duration of the flight, including ascent, burst, descent, landing, and recovery.

The recorded footage was segmented into 45-minute intervals, resulting in a total data volume of approximately 132 GB stored on the camera's internal storage. After post-processing, including editing and resolution reduction, the final compiled footage was reduced to 8 GB with a total duration of 2 hours and 6 minutes.



Figure 4: Redesigned payload strung on flight string prior to payload launch

The Raspberry Pi system did not operate as intended. Post-flight inspection of the onboard storage indicated that the recording script was never executed. Further investigation showed that the camera module was not detected by the Raspberry Pi upon boot.

Two primary failure modes are considered. The first is mechanical damage to the camera module during transport or flight, resulting in a loss of communication with the Raspberry Pi. The second is electrical failure, potentially caused by electrostatic discharge or environmental conditions at altitude, which may have damaged the camera module during operation.

In either case, the loss of camera detection prevented the execution of the recording script, resulting in a complete failure of the secondary imaging system.

The thermal insulation was effective in its goal, though may have had too much of an effect. Inspection revealed signs of delamination of the insulation from the box, mainly caused by the ambient heat present in the payload. Contributing factors for this result may include the size and power of the Raspberry Pi model chosen, the batteries present, or the dark shade of filament chosen for the final box fabrication.

The redesigned payload achieved the major objective of the project. Camera movement was successfully minimized during the launch, providing the desired footage. Thermal performance was also adequate, with both the action camera and onboard electronics operating under low-temperature conditions during ground testing.

However, the intended system-level redundancy was not fully achieved due to the failure of the secondary imaging system. All this came at the cost of a heavier payload with components that provided no data from the launch.

8 Future Improvements

Several areas for improvement have been identified based on these results. The most significant improvement involves the on board electronics. The choices made were built on the concept of having a secondary visual recording system. With these results, the backup may not be necessary. Future concepts may downscale to a smaller Raspberry Pi model or revert back to the CU Boulder payload kit internals. Reflection on the design suggests that the added weight and complexity of the secondary recording system may not provide sufficient benefit.

Thermal management should also be refined to better balance heat retention and heat dissipation. While the insulation effectively protected components from low external temperatures, internal heat buildup resulted in visual heat artifacts. Future iterations may benefit from controlled ventilation, alternative insulation materials, or adjustments to internal component placement to reduce localized heating. Future models also could explore the possibility that the Filament is enough of an insulator for the applications of a balloon payload.

Further improvements can be made to the structural design to enhance manufacturability and assembly. While the current design reduced camera movement and improved durability, consideration of modularity and ease of access to internal components would simplify assembly, maintenance, and future modifications.

These reflections provide a clear path forward for another team to improve this design in the future.

9 Conclusion

This project presented the redesign, fabrication, and evaluation of a high-altitude balloon imaging payload intended to improve upon previous projects developed at Pikes Peak State College. The primary objectives of the redesign were to improve structural reliability and increase system reliability while maintaining manufacturability for future student teams.

The redesigned structural system successfully addressed prior issues related to camera movement and mechanical instability. Ground testing and flight results confirmed that the payload maintained structural integrity throughout the duration of flight. The primary imaging system operated continuously and successfully captured the full mission.

However, the secondary onboard imaging system did not perform as intended due to a failure in the Raspberry Pi camera detection. As a result, the intended data collection was not fully achieved. This limitation highlights the importance of improving electrical systems and acknowledging when complexity does not need to be introduced.

Thermal performance was generally successful in protecting onboard components under extreme environmental conditions, although internal heat buildup and insulation behavior indicates that further refinement is needed. Manufacturing and assembly processes also demonstrated the effectiveness of prototyping, while revealing opportunities for improved modularity.

Overall, the redesigned payload represents a significant improvement in structural design and imaging reliability compared to the previous system. While not all design goals were fully achieved, the project provides a strong foundation for future iterations and establishes clear guidelines for development of additively manufactured payloads.

A Appendix

A.1 Technical Drawings

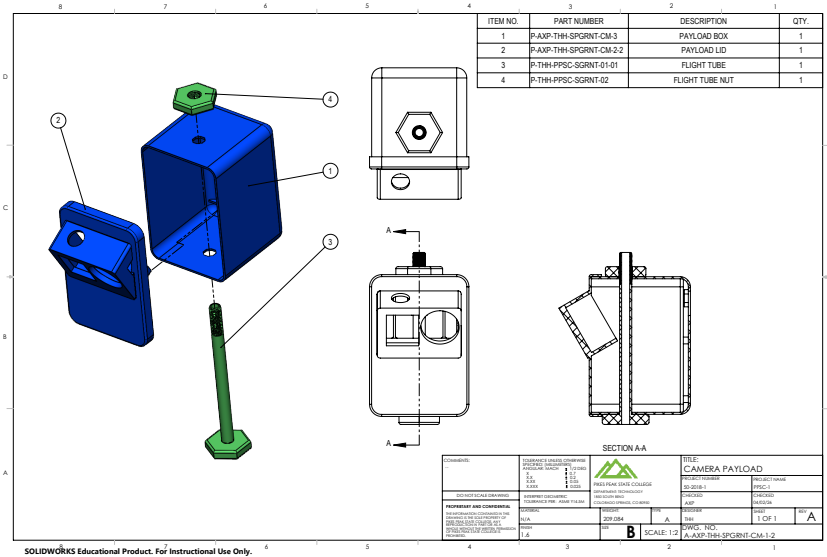


Figure 5: Assembly drawing of the redesigned payload

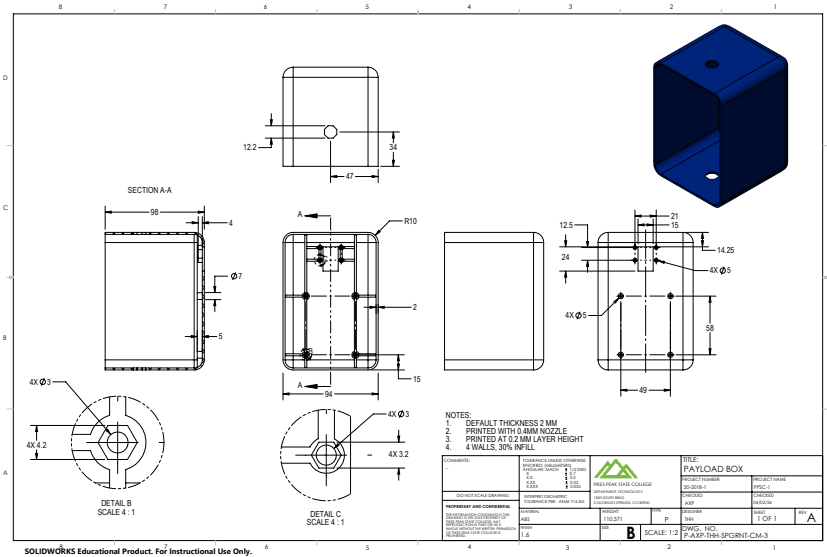


Figure 6: Drawing of main structure for the payload

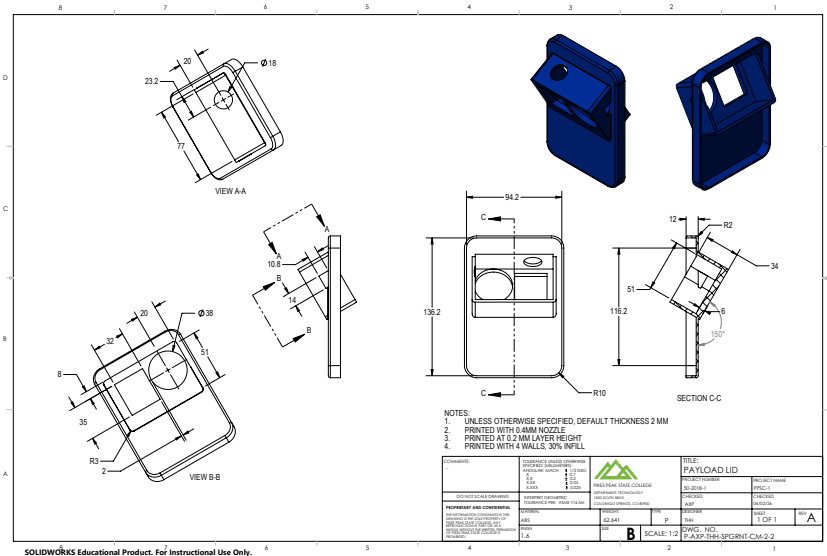


Figure 7: Drawing of lid for the payload

A.2 Additional Photos



Figure 8: First Landing picture taken at recovery site

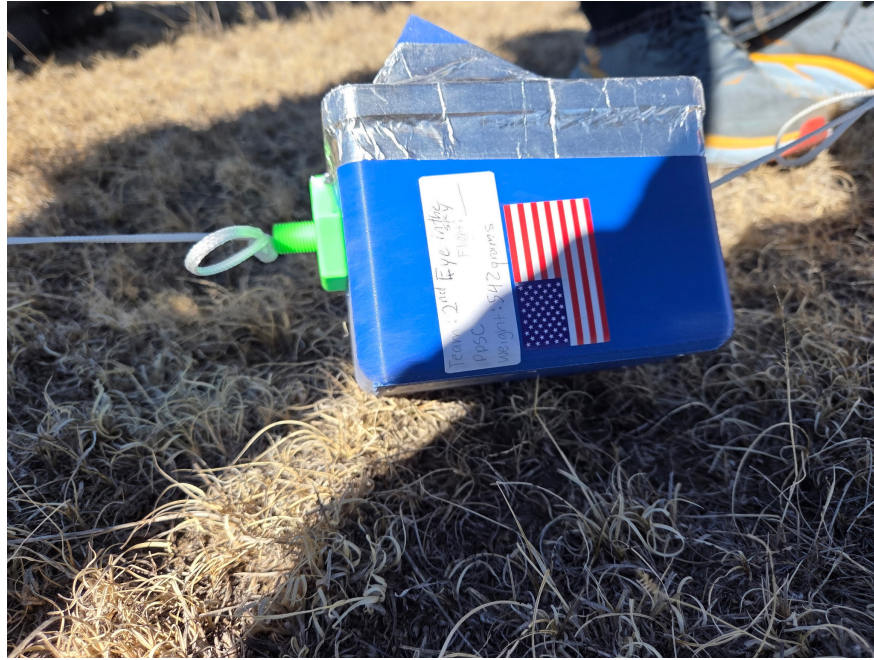


Figure 9: Second recovery picture taken at recovery site

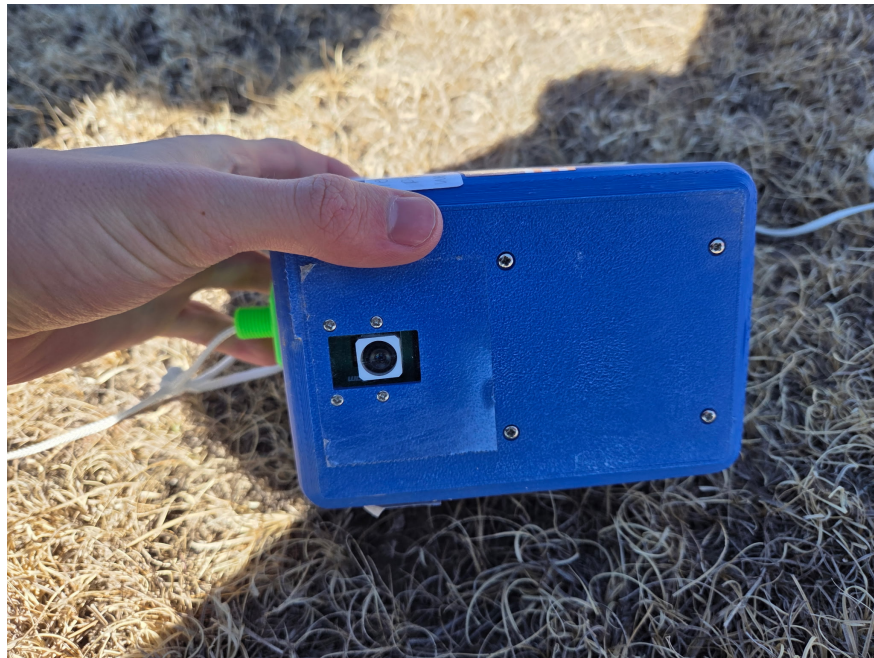


Figure 10: Third recovery picture taken at recovery site

B Bill of Materials

Component	Description	Quantity	Notes
DJI Action 6 Camera	Primary external imaging system	1	Main flight recording camera
Raspberry Pi 4B	Onboard computing system	1	Controls secondary imaging system
Arducam 64MP Module	Secondary onboard camera	1	Backup imaging system (flight unused)
Battery HAT + Li-Ion Cells	Power supply system	1 set	Powers Raspberry Pi and peripherals
ASA Filament (1 kg spool)	Structural material for enclosure	1	3D printed payload housing
Fasteners (M2 and M3 hardware)	Mounting hardware	Set	Standoffs, screws, nuts
Thermal Foam	Insulation material	Set	Internal thermal lining
Paracord Interface	Flight suspension system	1	Connects payload to flight string
CU Boulder Sensor Kit	Legacy atmospheric system	1	Not used in final flight
Misc. Electronics	Wiring, SD cards, connectors	Set	Supporting components

Table 1: Bill of Materials for redesigned high-altitude balloon payload

References

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