Video Streaming with the Raspberry Pi 5

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Live video streaming from high-altitude balloons has been a challenging but rewarding hurdle for ballooning teams across the nation participating in the Nationwide Eclipse Ballooning Project to overcome over the past eight years. Here, we present our findings on using the Raspberry Pi 5 (RPi5) with dual camera ports as the single-board computer powering the live video payload on the balloon. The cameras utilized 3D-printed mounts to orient the two wide-angle cameras to make the ground and horizon visible with minimal overlap. The dual RPi5 camera streams require a large amount of processing power and energy. The software running on the RPi5 was the only significant independent variable that could be configured. A battery life and long-range distance test were conducted with the streaming setup, which allowed the batteries to run until they drained, which lasted about three hours and thirty minutes. During the eclipse, the video was successfully streamed from the balloon to the ground station, which had a maximum range of about 24.3 miles. Although the picture quality was clear, the video stream was choppy. Initial analysis suggests the dropped frames could be related to suboptimal stream configuration or external signal interference. The batteries powered the video payload for the entire flight. However, the full extent of the battery life in flight was not tested because the balloon burst before floating. Overall, video streaming from the RPi5 with dual camera ports was a success, although further testing is required to determine the cause of the choppy video.

Live video streaming | Raspberry Pi 5

Acknowledgments

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Introduction

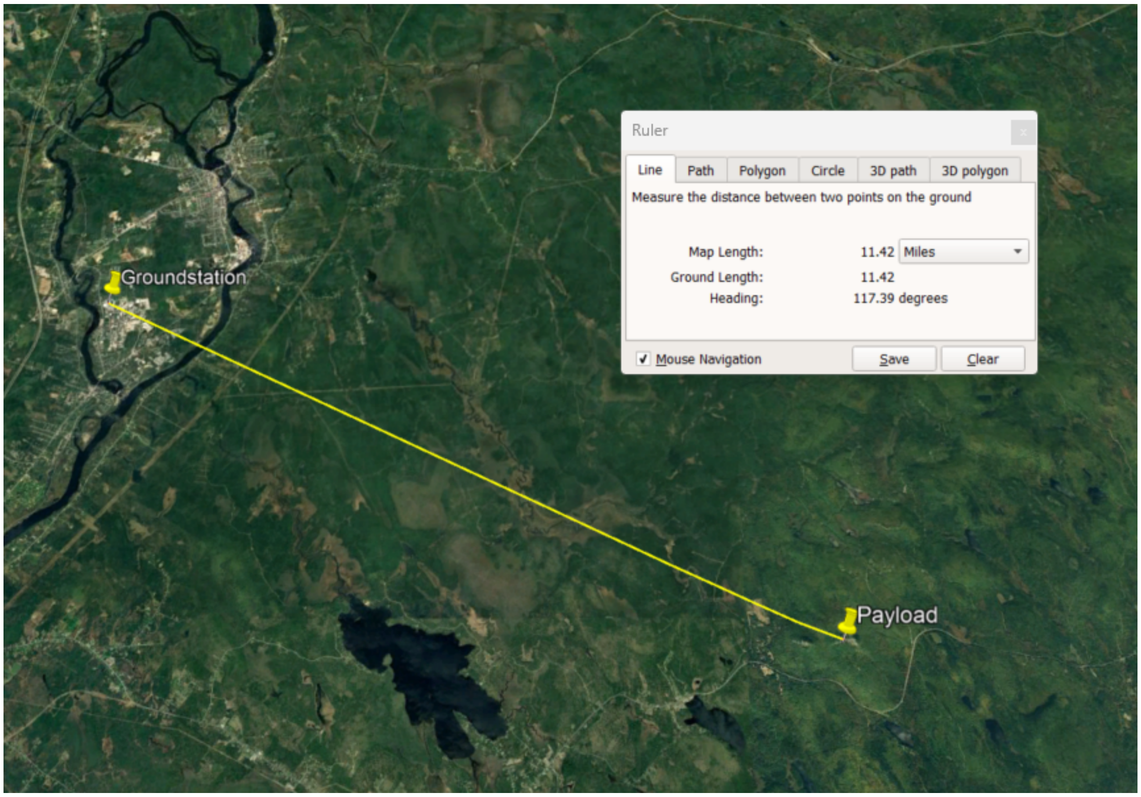
The University of Maine High Altitude Ballooning (UMHAB) team participated along the NEBP engineering track, focusing heavily on the live video streaming payload. The UMHAB team investigated the performance and viability of powering the live video streaming payload with the newly released Raspberry Pi 5 (RPi5). The live video streaming payload was previously based on the Raspberry Pi 4 (RPi4). This paper discusses the design and testing of a high altitude balloon video payload system that utilizes the RPi5 with dual camera ports as the onboard computer.

Hardware Setup

The video payload's physical design utilizes 3D-printed mounts, a metal ground plane, and various connection hardware in addition to the electronic components, as shown in Fig. 1. Both cameras have a maximum vertical field of view of 102°, so it was decided to angle them 50° from downwards to view as much of the sky as possible while maintaining a small area of overlap in the middle. This was done using 3D-printed camera mounts that could stick out of the payload box and point downwards at the desired angle. The RPi5 and power board are both mounted to the metal ground plane with a 3D-printed mount. This allows both boards to sit perpendicular to the metal ground plane, reducing their footprint. The Ubiquiti Rocket modem is mounted with the antennas through the metal ground plane, allowing the antennas to be at the bottom of the box and unobstructed by other components of the payload. Lastly the batteries are mounted to the plane with a metal cover holding the batteries in place and close enough to connect to the power board.

Fig. 1. Video payload physical design without box.

Fig. 2. View of Peaked Mountain from campus bleachers.

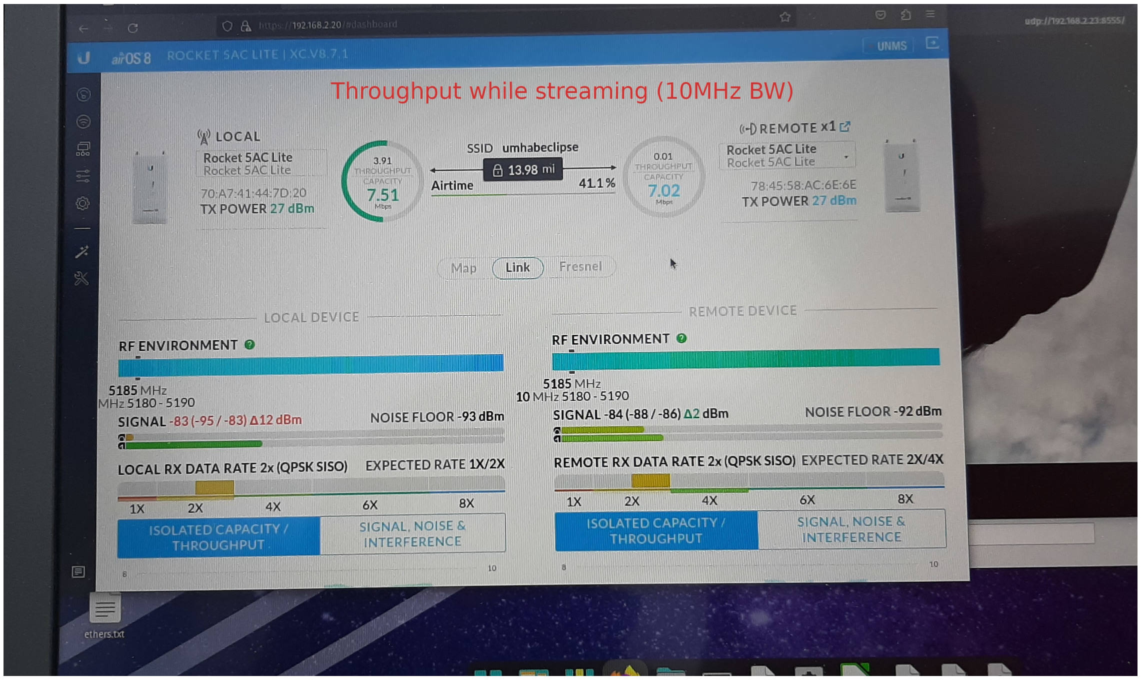


Measure the distance between two points on the ground

Map Length: 11.42 Miles
Ground Length: 11.42
Heading: 117.39 degrees

☑ Mouse Navigation

Fig. 3. Distance from the ground station to the payload during the test.



LOCAL
Rocket 5AC Lite
Rocket 5AC Lite
70:A7:41:44:7D:20
TX POWER 27 dBm

3.91 THROUGHPUT CAPACITY 7.51 Mbps

SSID umhabeclipse
13.98 mi
Airtime 41.1 %

0.01 THROUGHPUT CAPACITY 7.02 Mbps

REMOTE x1
Rocket 5AC Lite
Rocket 5AC Lite
78:45:58:AC:6E:6E
TX POWER 27 dBm

LOCAL DEVICE
RF ENVIRONMENT
5185 MHz
10 MHz 5180 - 5190
SIGNAL -83 (-95 / -83) Δ12 dBm
NOISE FLOOR -93 dBm
LOCAL RX DATA RATE 2x (QPSK SISO)
EXPECTED RATE 1X/2X

REMOTE DEVICE
RF ENVIRONMENT
5185 MHz
10 MHz 5180 - 5190
SIGNAL -84 (-88 / -86) Δ2 dBm
NOISE FLOOR -92 dBm
REMOTE RX DATA RATE 2x (QPSK SISO)
EXPECTED RATE 2X/4X

Fig. 4. Video stream signal strength measured from the ground station.

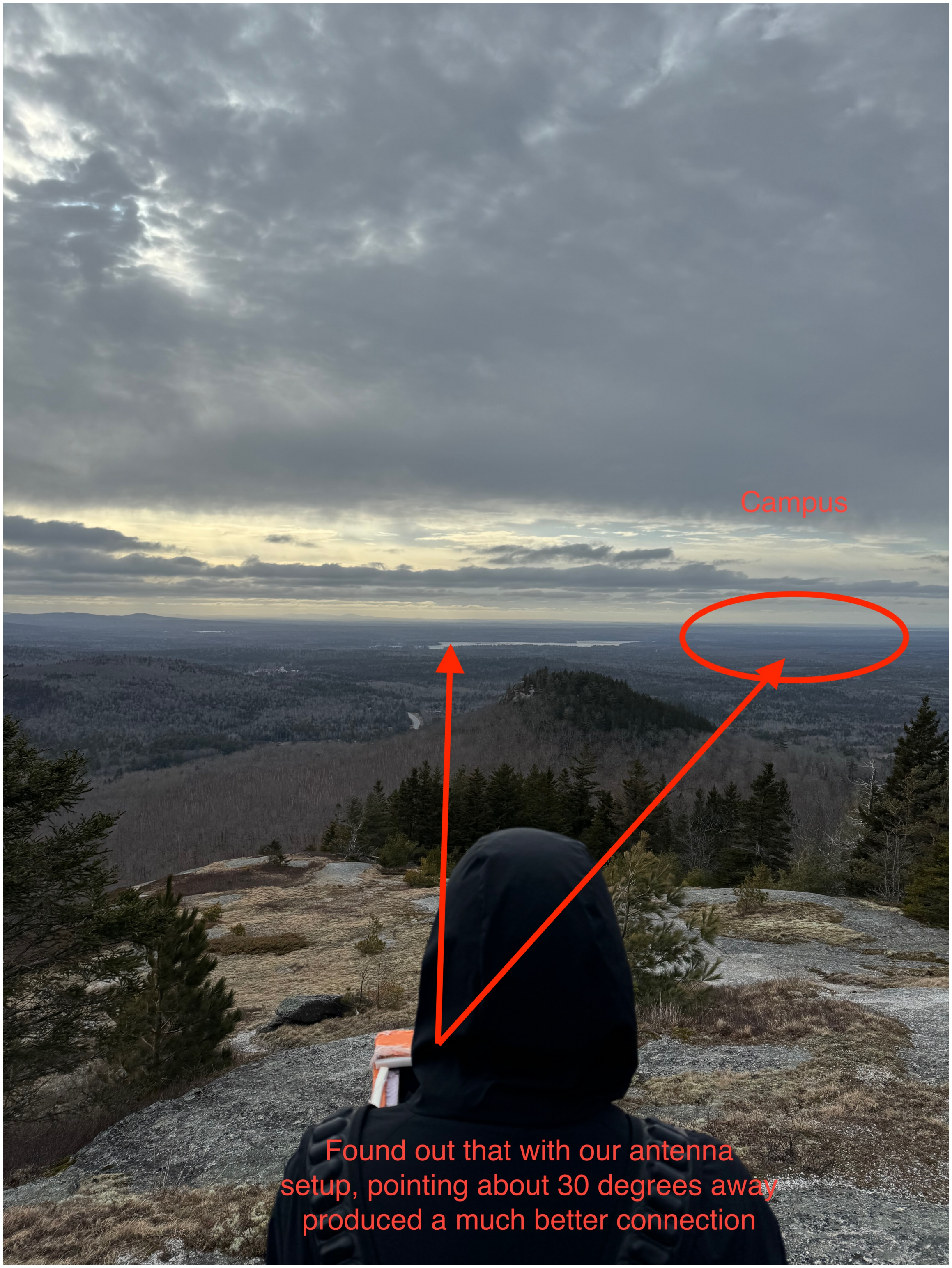


Fig. 5. View of optimal box orientation from Peaked Mountain.

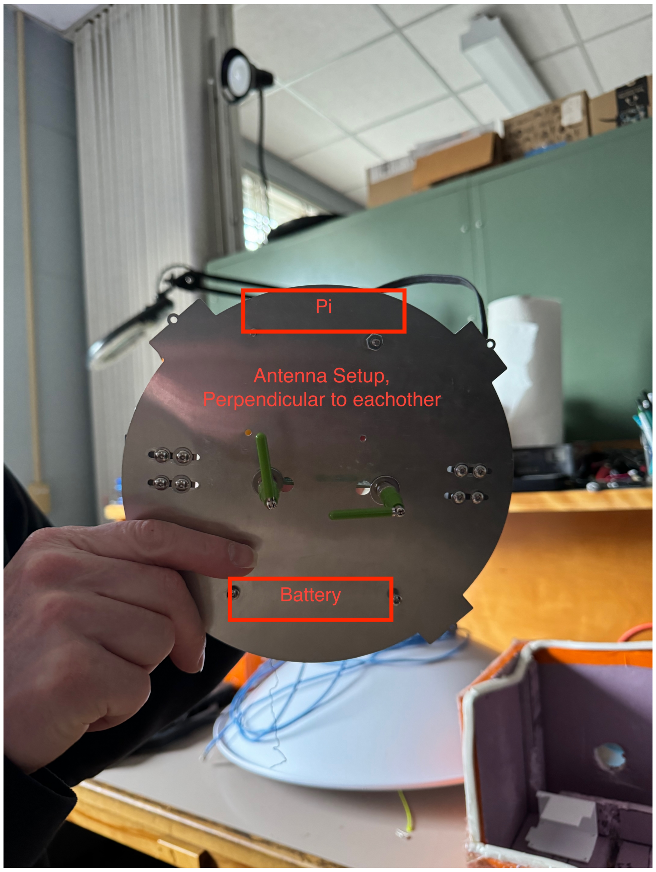


Fig. 6. Antenna setup on video payload.

Software Setup

The camera ports on the Raspberry Pi 5 operate similarly to the single camera port on the Raspberry Pi 4 and allows for an analogous software configuration. The dual camera streams, combined with higher-resolution camera outputs, increase the transmitted pixel count by more than double than that of the ArduCam setup. The increased volume of video data requires substantially more processing power and energy. A large amount of time was invested in optimizing the video communication between the cameras and the ground station to address the energy consumption. Due to the hardware largely being off-the-shelf parts, the software is the only significant independent variable that could be configured to meet the limited requirements. The hardware creates a power constraint for the live video streaming payload. Reducing the framerate is one method of decreasing the processing load. After experimenting with a variety of frame rates, the best balance between computational load and smoothness was found to be 12 frames per second. The video's bit rate was the other variable that was experimented with, landing at 1.2 Mbps for each stream.

Testing

Several long-range tests were conducted in preparation for the 2024 solar eclipse to investigate connectivity between the payload and the ground station. One party climbed a local mountain that has a line of sight with the University of Maine campus shown in Fig. 2 roughly 11.42 miles away shown in Fig. 3. The best direction to point the video payload antennas was determined by pointing the payload in various directions and observing the signal strength shown in Fig. 4. The best direction was found to be pointing 30° away from the ground station as shown in Fig. 5. The antennas were also adjusted to find the best orientation shown in Fig. 6. Battery life was tested with the streaming setup, allowing the batteries to run until they drained, which lasted for about three hours and thirty minutes.

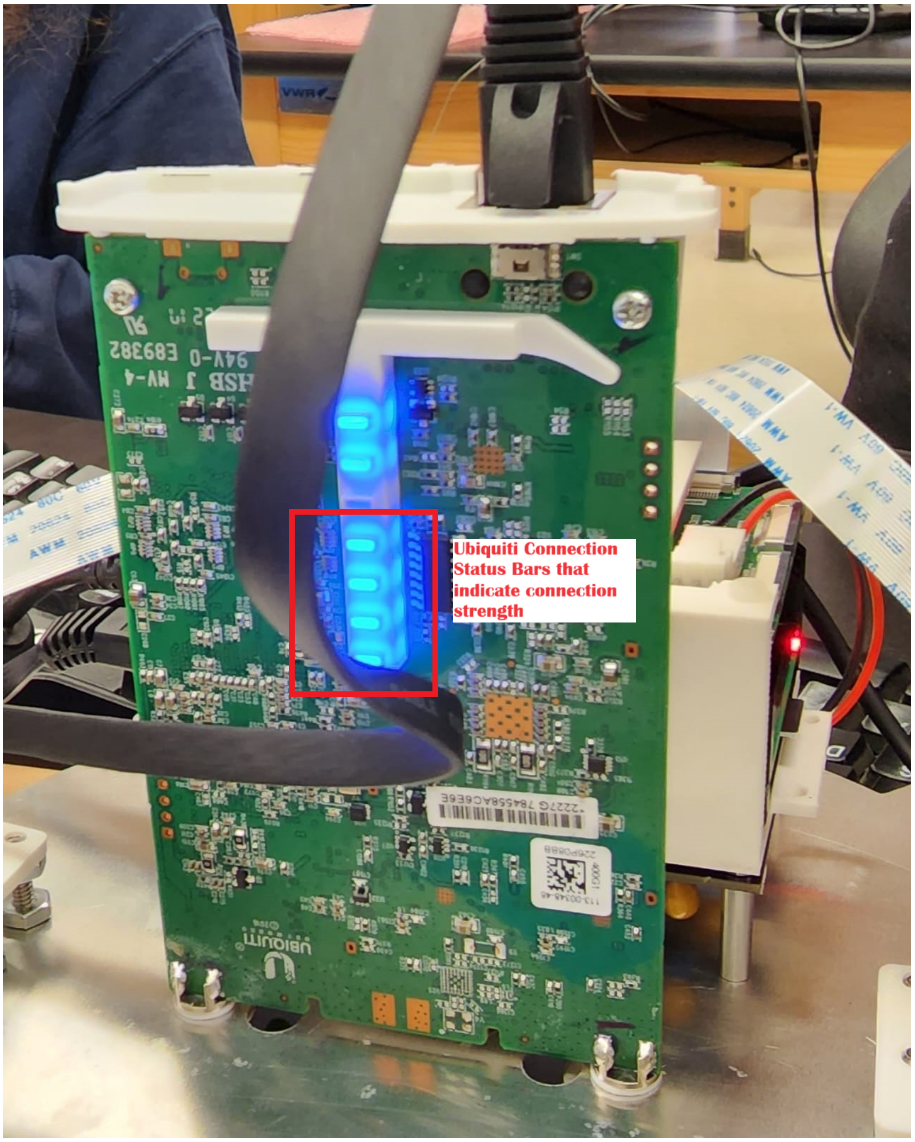


Fig. 7. Ubiquiti Rocket onboard the video streaming payload used to stream video to the ground station

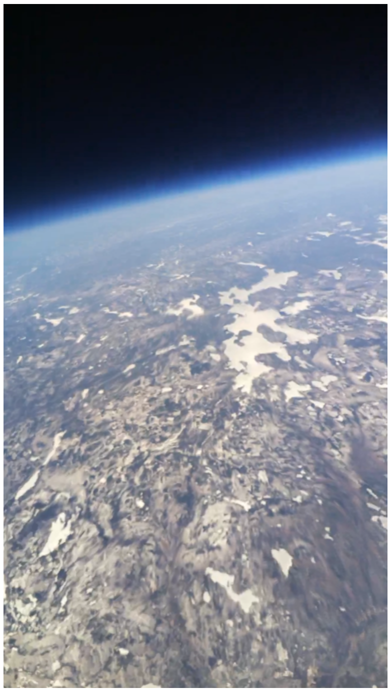


Fig. 8. View from video payload during ascent.

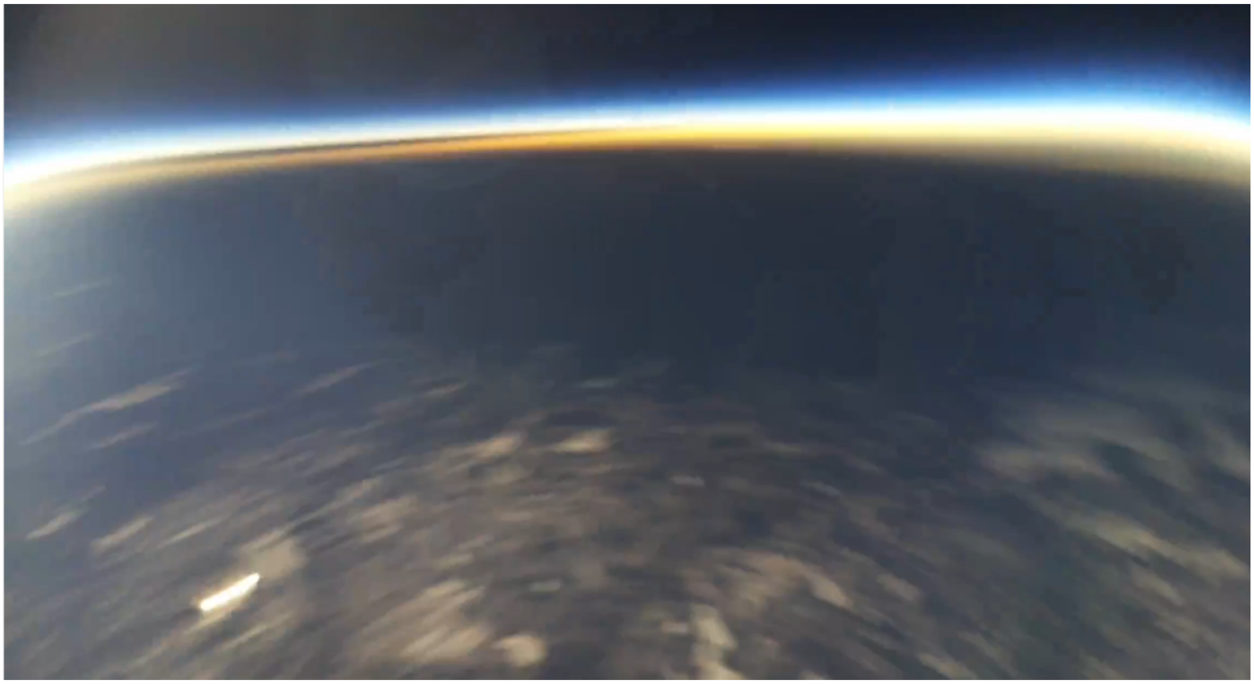


Fig. 9. Shadow cast on the Earth as captured by the RPi5 video payload

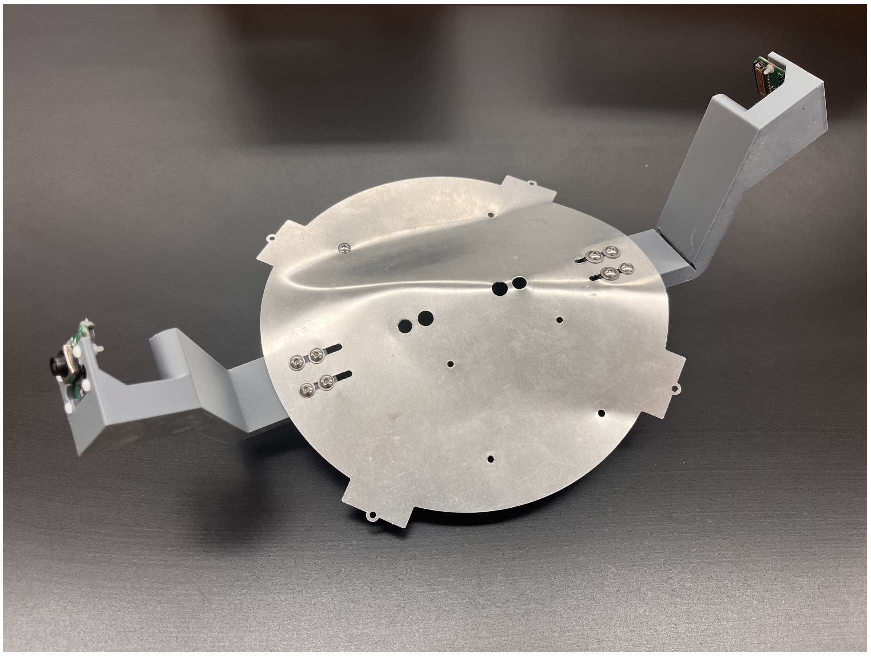


Fig. 10. Damage to video payload after landing.

Eclipse Day

A total solar eclipse was observed in the United States on April 8, 2024, and the team aimed to successfully stream a live video feed of the moon's shadow cast on the Earth. During the eclipse, the video was successfully streamed from the balloon to the ground station, which had a maximum range of about 24.3 miles. Although the picture quality was clear, with a consistent 2-3 signal bars (out of 4 total bars as seen in Fig. 7) on the Ubiquiti modem, the video stream was choppy. Initial analysis suggests the dropped frames could be related to sub-optimal stream configuration or external signal interference. The batteries powered the video payload for the entire flight. However, the full extent of the battery life was not tested because the balloon burst before a float could be established using the onboard Iridium-controlled vent. Fig. 8 shows the video recorded from the payload during ascent from one of the cameras. Fig. 9 shows the video recorded from the payload shortly before the shadow passed over the balloon. This frame was taken on the payloads' descent as the balloon burst about four minutes before totality.

Future Work

The the Raspberry Pi 5 based live video streaming payload would benefit from further optimization of the operating system running the software. Raspberry Pi OS is a general purpose operating system with a lot of features and functionality that are irrelevant to a headless and battery operated setup. An investigation into the processes that run in the background and could be disabled would be beneficial in reducing memory and load on the RPi5. For teams that are launching balloons and have an extra buffer in terms of mass of the payloads before hitting the maximum payload capacity, a solution to the shortened battery life is to add more batteries. The physical design of the payload can be redesigned with a new battery power board to allow the addition of more than six 18650 batteries. An example redesign follows a modular battery system that utilizes a stacking method to build a battery stack. The design incorporates two 18650 battery holders, each of which holds two cells. This kind of design would allow a longer and more compact payload box to be used, along with allowing for more cells. Another feature that could be explored is the addition of a servo motor that can be remotely controlled to position the camera at the ideal angle based on the current conditions. This could allow the camera to be positioned to view both the eclipse and the shadow. As shown in Fig. 10 the payload got too damaged to be reused after landing. Improving the strength of the physical design could help resolve this issue, reducing the amount of repairs that need to be made in between launches.

Conclusion

Overall, video streaming from the RPi5 with dual camera ports was a success. The RPi5 enables a higher-resolution dual-view live stream from a high-altitude balloon at the expense of battery life. Additionally, the swap from the RPi4 to the RPi5 does not require any major hardware redesigns. Further testing is required to determine the cause of the choppy video experienced during the April 8th, 2024 flight.