Arizona Space Grant Consortium Participation and Contribution During the 2017 Solar Eclipse

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Students from the Arizona/NASA Space Grant Consortium attended the Montana State University (MSU) Solar Eclipse Workshop in July 2016, where the MSU-designed ground station and payloads were assembled. The team returned with the systems, making modifications and conducting tests leading up to the eclipse in the following areas: ground station tracking and payload improvements, including expanded video capability. With the initial aid of Louisiana State University (LSU), the team upgraded the tracking system to use both Automated Packet Reporting System (APRS) beacons and MSU's Iridium tracking system. This update improved the accuracy of determining the location of the balloon and payloads. The hardware improvements for the ground station included the addition of mobile HughesNet satellite internet service. Payload improvements included using medium-gain antennas, next generation Ubiquiti modems, and Raspberry Pi 3 computers. In addition, a 360 degree video camera payload was developed. The systems were tested over six balloon flights. During the solar eclipse, the team was in Glendo, WY, and flew the following payloads on two balloons: Digital Video Payload (DVP), Digital Image Payload (DIP), 360 Video Payload, Arizona State University (ASU) Scientific Payload, flight termination payload, and tracking payloads. Each of these payloads functioned correctly with the exception of DVP, possibly due to damage at launch, which meant the team was unable to live stream video during the eclipse. Instead, the team streamed an image slideshow to a NASA website during the eclipse with still images downlinked from the DIP. However, videos from both the DVP and 360 Video Payload were recovered after the flight and later processed. Overall the mission was successful in collecting video, images, and data of the eclipse from the high-altitude perspective.

I. Introduction

THE project described in this paper is Arizona/NASA Space Grant Consortium's (AZSGC) participation in NASA's Nationwide Eclipse Ballooning Project, led by Montana State University (MSU). The primary mission was to provide NASA a live video streaming source of the moon's shadow crossing the earth from a high-altitude balloon during the total eclipse on August 21, 2017. The secondary mission was to provide students with the opportunity to develop and fly balloon-based scientific instruments to observe effects of the eclipse.

The AZSGC team consisted of students and faculty from Embry-Riddle Aeronautical University (ERAU), Prescott, and Arizona State University (ASU), Tempe. ERAU students worked with the primary mission payloads: Digital Video Payload (DVP), Digital Image Payload (DIP), Iridium Tracking Payload (ITP), and Cutdown Payload, and developed the 360 Video Payload to locally save high-resolution video. ASU was responsible for developing a scientific payload.

The primary mission equipment was initially developed by MSU. ERAU students made several improvements to the ground station and the payloads after initially receiving MSU's equipment at a July 2016 workshop. AZSGC flew two-high altitude balloons on eclipse day from Glendo, WY. Flight logistics and flight support were provided by Arizona Near Space Research (ANSR).

The purpose of this paper is to share the design changes, both software and hardware, made by students at ERAU on the AZSGC team to improve the tracking and payload systems originally furnished by MSU. The authors make recommendations for design improvements based on their experiences. Further, results and gathered media from eclipse day are included in this paper.

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II. Ground Station

One aspect of system improvements was precision and reliability of the ground station's tracking of the balloon. The original ground station system and the AZSGC modifications are described below.

A. Original Ground Station Tracking

The original tracking system consisted of a single GPS beacon, known as the Iridium Tracking Payload (ITP), that was connected to the ground station via the Iridium satellite network. The ground station would automatically retrieve the Iridium location data from a website created by MSU, determine the pointing direction of the antenna dish to receive broadcasted media, and active servo motors to control the antenna's elevation and azimuth angles. Data packets were usually retrieved between 30 seconds and 5 minutes apart. On a test flight in October 2016, the time between two data packets from Iridium was 10 minutes. This test flight highlighted the importance of improving the rate at which the balloon's position data was updated to improve ground station pointing accuracy.

B. Tracking Improvements

The original system provided a great starting point for research and development. The largest changes made were in software. The original code for the tracking system was completely replaced with code received from Louisiana State University (LSU) to allow for tracking with both the Automated Packet Reporting System (APRS) and the original Iridium system.

The new system reliably provided updates on position every thirty seconds from APRS beacons, while also adding in the occasional packet from Iridium. More frequent update of the balloon's location provided more accurate tracking. AZSGC modified the LSU tracking version to match the format of APRS packet used by ANSR.

APRS beacons provided by ANSR were flown on each balloon's payload chain. A GPS module inside the beacon collects position data, which is then converted into a National Marine Electronics Association (NMEA) string. The string is then sent via a non-confirmation receive packet, which means anyone can receive the packet. The packet is received by the ground station via VHF radio transceiver and interpreted by a Terminal Node Controller (TNC) to be sent to a computer running a command line. A possible addition to the system includes taking APRS beacon information from the internet in case the beacons are outside range of ground station radio.

Furthermore, the AZSGC team made tracking software more robust by adding multiple fail safes. The user could disable the sources the ground station was using to track the balloon's location in case one APRS beacon or the ITP failed during flight. The user was also given the option to manually input coordinates of the ground station's static location, since slight variations of the ground station's GPS location data provided by the Arduino's IMU decreased precision.

C. Additional Modifications

Only minor hardware changes were implemented to the system. The most important to note is the 900 MHz patch and Yagi antennas were removed from the original MSU system, since the Digital Image Payload was changed to transmit images on 2.4 GHz. Due to weight and size restrictions on AZSGC's system, ANSR allowed AZSGC to modify their ground station to mount a 2.4 GHz dish antenna for receiving images from DIP. ANSR's system used the same APRS beacons for tracking as AZSGC's system.

Furthermore, to improve the quality of the stream from the ground station to the internet, ANSR provided mobile HughesNet satellite internet at the ground station rather than relying on 4G wireless service. This provided a less congested route and expanded the capability to set up a ground station at more rural sites.

III. Payloads

The following section outlines the changes made to the Digital Video Payload (DVP) and the Digital Image Payload (DIP) and the development of the additional 360 Video Payload.

A. Digital Video Payload

The hardware changes to the DVP included the use of Ubiquiti's 5AC, 5.8 GHz WiFi transceiver and a higher-gain, L-Com patch antenna. These changes were justified for the need to improve the video quality of the streamed media. Ground tests showed the changes improved ground station gain in signal by 5dB, which improved video quality (i.e., the video was less grainy/pixelated). The DVP flown during the eclipse is shown below in Figs. 1 and 2.

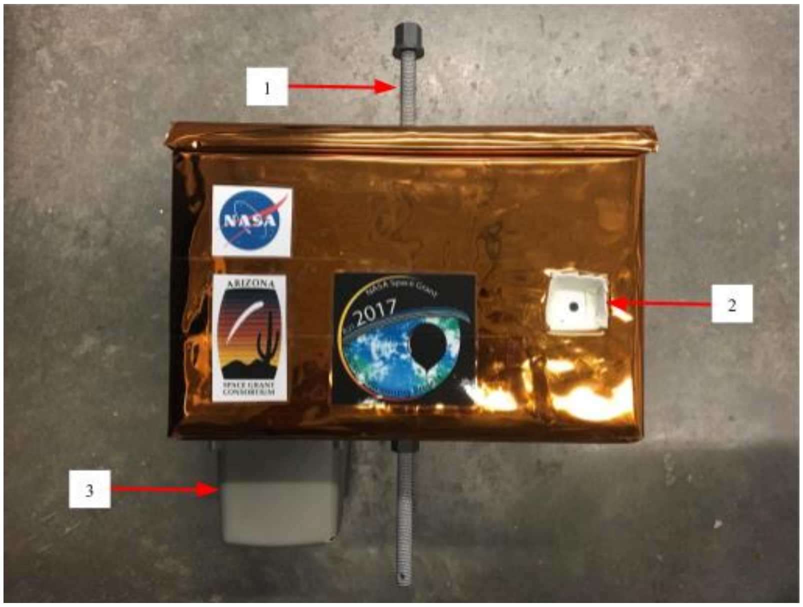

Figure 1. External view of the Digital Video Payload. Call-out 1 indicates the carbon fiber rod that is used to tie the payload to the main string, 2 indicates the Pi camera used to capture video, and 3 indicates the L-Com antenna used to transmit video.

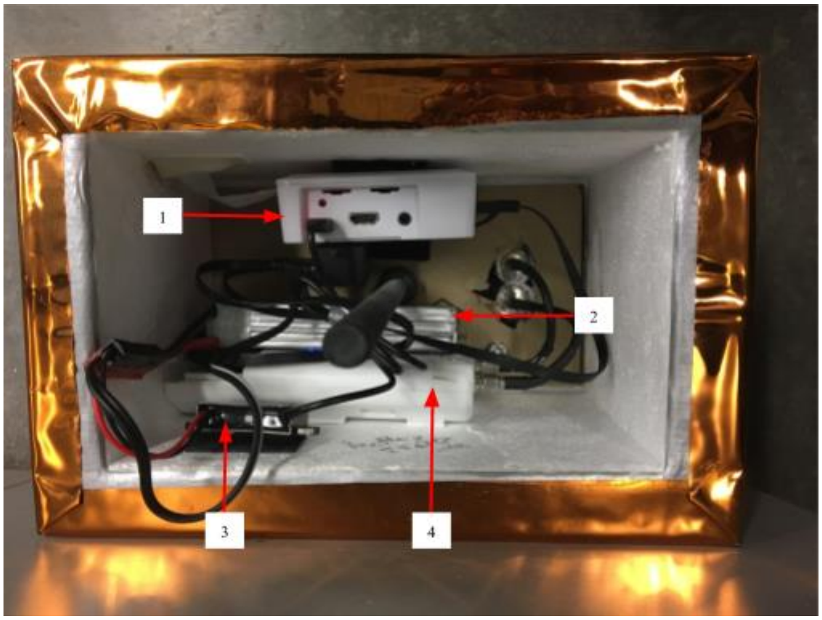

Figure 2. Internal view of the Digital Video Payload. Call-out 1 indicates the housing for the Raspberry Pi 3 microcomputer, 2 indicates the LiPo battery for the payload power source, 3 indicates the DC to DC power converter in series with the Pi and the battery, and 4 indicates the Ubiquiti 5AC 5.8 GHz Wi-Fi transceiver.

The main drawback with the new antenna was a narrowed main lobe with maximum gain within 15 to 20 degrees of the vertical. To receive optimal signal, the ground station's elevation angle to the balloon had to be greater than 70 degrees. However, during a test flight in conjunction with a nationwide test on June 20, 2017, AZSGC flew the DVP with the new hardware and demonstrated video could be streamed from an elevation angle about 7 degrees to 60 degrees near burst, about ten ground miles away from the ground station. As the balloon ascended, the ground station received radio signal from different lobes, which resulted in varying quality of video compared to central lobe signal.

Consequently, AZSGC team set the following flight parameters for the ground station to be within the main lobe during totality: at 80,000 ft the balloon should be within five ground miles of the ground station. ANSR provided flight support and ran predictions to get a flight profile within the parameters by selecting an appropriate launch site. Due to both a delayed launch time and a power failure with the WiFi transceiver, the AZSGC team was unable to stream video during the eclipse.

To assist stabilizing the payload against rotation, rods with foam balls attached to the ends were mounted to the top of DVP in four directions, 90 degrees apart, similar to the “air scoops” described by Flaten et al [1]. The idea for the anti-rotation stabilizer system was to increase drag around the payload to make the dominant forces in the vertical direction. However, this passive stabilization method is limited to lower elevations where the atmosphere is denser.

B. Digital Image Payload

The main improvement to the DIP included controlling a servo to rotate a Pi Camera to two positions to view the moon’s shadow on the Earth during the eclipse: horizontal (i.e., facing toward the horizon) and down-facing (i.e., pointing toward Earth’s surface). The servo rotated every fifteen seconds to either position. Originally, the camera was built to aim and capture images only in the down-facing position.

Provided the limited field of view on the Raspberry Pi Camera, the team concluded that the images would not be able to capture the horizon in the down-facing position. Thus, during totality, the images would be of a dark Earth, without much detail. The horizontal view provides greater perspective of the shadow on the earth and can capture the moon’s shadow outside the few minutes of totality (i.e., before and after the shadow reaches the balloon’s location).

One limitation of this design is using Pulse Width Modulation (PWM) to control the servo attached to the camera. Even while in the final positions, the servo has jitter, or small oscillations, which can cause blurriness in the image.

As previously mentioned, rather than transmitting images using the RFD900 modems on 900 MHz, AZSGC team used the Ubiquiti Rocket M2 modems to transmit on 2.4 GHz. The higher frequency increased bandwidth, and the modems tested 5 dB gain over the RFD900 during a ground test.

C. 360 Video Payload

ERAU students on the AZSGC team built a secondary video payload to capture 360 video of the eclipse from the high-altitude perspective. The 360 video means 360 degrees azimuth angle and 100 degrees elevation angle. The payload sat at the bottom of the payload chain (i.e., farthest from the balloon) with similar vertical stabilizers as used with the DVP. The payload included a Kodak 4K 360 video camera and an additional battery pack in series with the camera’s battery.

The 360 video was saved locally and recovered after landing (i.e., not streamed). While the DVP’s Raspberry Pi Camera provided an excellent source for streaming due to file size, the camera was limited in capturing the eclipse from only the plane of view in which the camera happened to be pointed. On the other hand, the 360 video provided an excellent source to view the Earth below due to horizon-to-horizon capture.

IV. Results

The team was successful in live streaming images, though not video, of the eclipse. At no time during flight, could connection be established with the DVP, thus video was not streamed. Connection to the DIP was established before totality and still images were downlinked throughout totality. Both the DVP and DIP were flown on the first balloon and reached at altitude of 60,000 ft during totality, and the 360 Video Payload was flown on the second balloon and reached an altitude of 40,000 ft during totality.

Videos from both the DVP and 360 Video Payload were collected after the balloons were recovered (i.e., were saved locally during flight. In total, AZSGC recovered over 400 images from DIP, 100 minutes of video from DVP, and 50 minutes of video from the 360 Video Payload.

A. Primary Payloads

The DIP and DVP were flown on the same balloon, and both the AZSGC and ANSR tracking systems functioned properly. Connection with the DIP was established successfully once the balloon reached 25,000 ft, and signal strength improved as the balloon increased in altitude. The team downlinked still images starting 20 minutes before totality. However, all efforts to connect with the DVP failed including attempts to ping the DVP’s Ubiquiti transceiver and, from there, the Raspberry Pi computer. Signal strength of the ground station transceiver attached to the dish antenna showed zero signal strength.

Upon recovery of the DVP, all wires appeared to be connected. After a reboot on the ground, the transceiver was functional and able to transmit signal. Video was recovered locally from the Raspberry Pi with recordings saved most notably 20 minutes before, during, and after totality, which means the Raspberry Pi was powered and properly working during the same window in which communication was attempted to be established.

During launch some of the payloads were mishandled in the rush of the event. The DVP was damaged on an impact during the balloon launch. At the launch site, the extent of the damage could only visibly be confirmed as damage to the anti-rotation stabilizers. However, the team suspects that the DC to DC power converter inside the DVP was possibly damaged, causing a power failure of the WiFi transceiver.

Instead of streaming video during the eclipse, AZSGC streamed a slideshow of still images downlinked from DIP to the Stream platform for NASA to publish publicly. Two images from the DIP are shown below, one from the horizontal position, shown in Fig. 3, and one from the down-facing position, shown in Fig. 4.

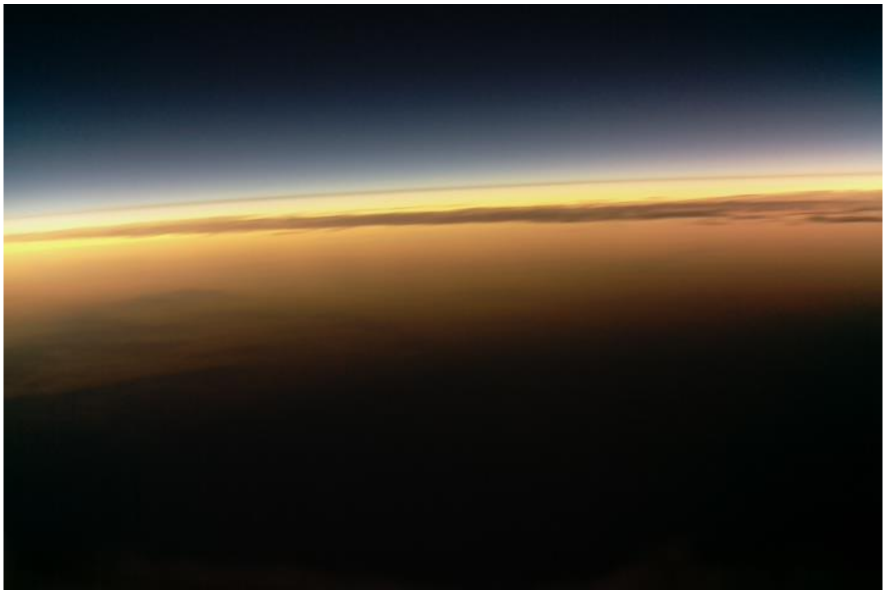

Figure 3. Image captured during totality from 60,000 feet with camera in the horizontal position. Moon's shadow is captured in the foreground.

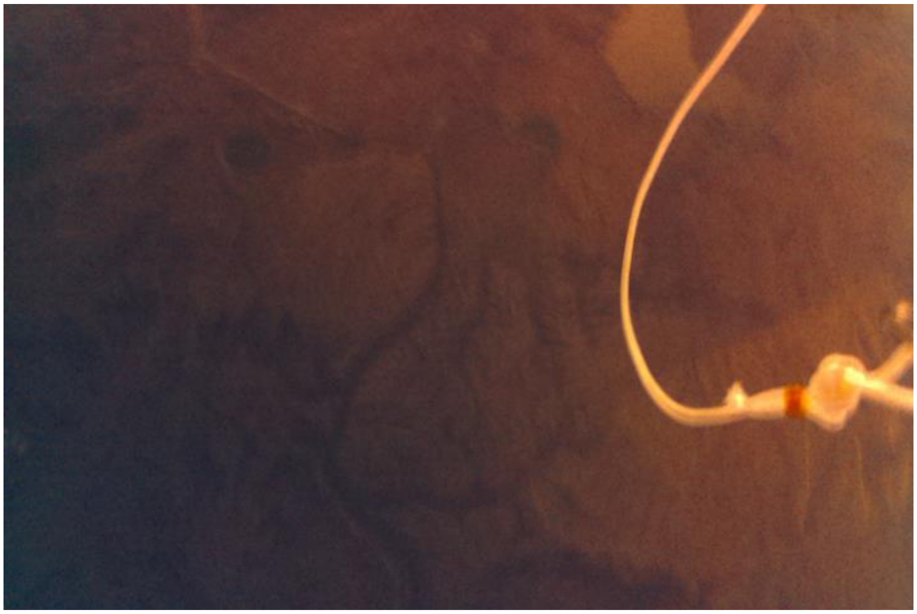

Figure 4. Image captured during totality from 60,000 feet with camera in the down-facing position.

Fig. 4 demonstrates the authors' motivation to rotate the camera between two positions, because during totality few details of the Earth's surface are distinguishable and only a portion of the shadow is captured.

B. 360 Video Payload

Over 50 minutes of flight time were recorded by the 360 Video Payload, including before, during, and after totality. The video of totality shows the moon's shadow enter from the northwest, move across the earth until totality at the balloon's location, and continue toward the southeast. The 360 Video Payload was flown on a second balloon different from the DVP and DIP. The launch of the second balloon was fifteen minutes after the first, which meant the second balloon only reached an altitude of 40,000 ft during totality.

Despite the effort to stabilize the 360 Video Payload with the anti-rotation stabilizers, the captured video was somewhat chaotic in that the payload (and camera) rotated about once every ten seconds. The original footage was difficult to observe the direction that the Moon's shadow passed. Post-processing of the 360 video was handled by Andras Szep and Marton Szep from the University of Arizona, Tucson, who had previously developed software to de-spin 360 video captured on high-altitude balloons. The edited video keeps the ground and immediate horizon stationary, resulting in a more comprehensible view of the event.

A sample image capture of the 360 video is shown below in Fig. 5. The image shows a capture of the 360 video about one minute before totality. The view is of the Earth below, and the apparent "ring" is the Earth's horizon, an effect caused by flattening to a two-dimensional view. The foam ball in the bottom of the image is part of the anti-rotation stabilizer.

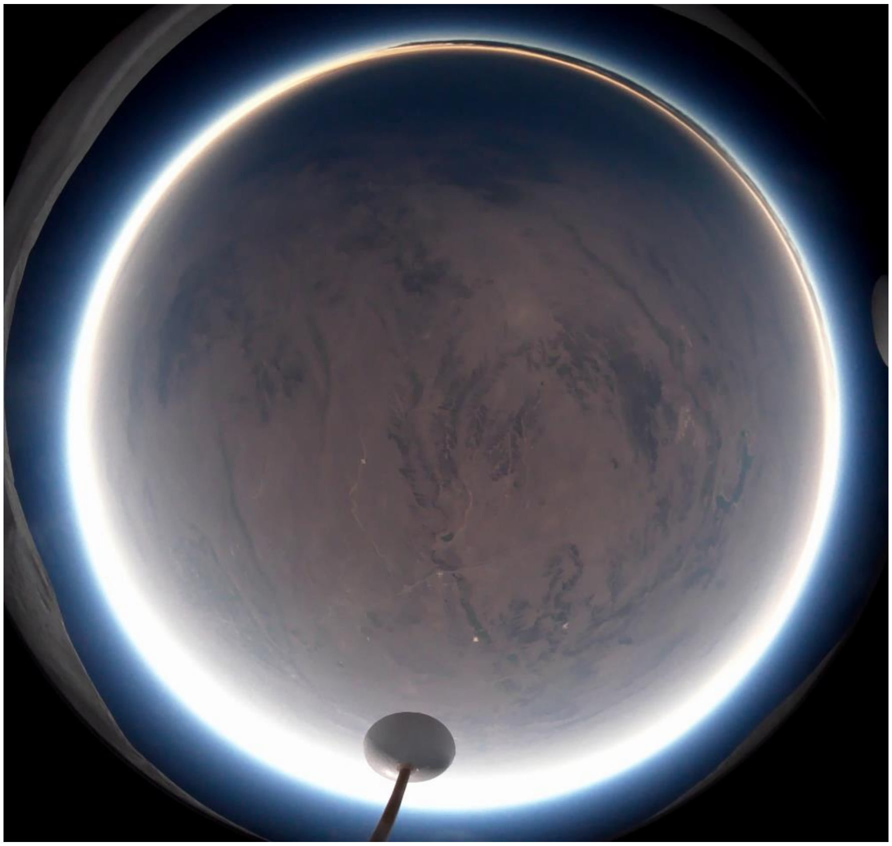

Figure 5. One frame from the 360 Video Payload Image. Approaching is the eclipse shadow visible on the (circular) horizon in the upper right.

V. Conclusion and Recommendations

The AZSGC team recommends the following improvements to the original MSU system: the addition of APRS beacons for tracking, multi-position cameras on the DIP, higher-gain antennae on the DIP and DVP, mobile satellite internet at the ground station, 360 video capabilities. Despite the failure of the DVP's transceiver, the AZSGC was successful in implementing the above recommendations.

Additional expansions of the MSU system for future projects may include video payload redundancy to increase the number of potential streaming sources; mobile or multiple ground stations capable of receiving the streamed video; and the ability to control the direction the camera faces, in both the DVP or DIP, with techniques described by Plewa and Scharlau [2].

Acknowledgments

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