Olin College and Boston College's High Altitude Balloon Flights During the 2023 Annular and 2024 Total Solar Eclipses

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Abstract

A combined team of students and faculty from Olin College and Boston College launched high-altitude balloons during the 2023 annular and 2024 total solar eclipses as part of the NASA-sponsored Nationwide Eclipse Ballooning Project (engineering track). This was the first ballooning experience for the team. For the October 2023 annular eclipse, a balloon was launched near Junction, TX, with the NEBP payload (Iridium tracking and control, RFD900, PTERODACTYL, and Raspberry Pi video steaming systems with the UMD vent/cut-down) and a custom payload (Geiger counter and system of four film cameras with an automated advance mechanism). The balloon reached a maximum altitude of 76,223 ft. After a flight of 2 hrs. 55 min., it landed 108 miles away with the balloon still attached to the parachute and payload. The cut-down circuit on the vent melted through the line but the vent sections did not separate. For the April 2024 total eclipse, the balloon was launched from Rocksprings, TX. The payload was the NEBP systems and a custom tracking package with four Raspberry Pi video cameras. Using a second, non-NEBP-design ground station, video from the custom package was livestreamed. This balloon was brought down after reaching 54,380 ft. It landed after traveling 162 miles in 2 hrs. and 10 min. Again, the balloon did not separate from the rest of the payload. Representative measured data and video images from both flights are presented.

NEBP | Eclipse | Total | Annular |

1. Introduction

In the fall of 2022, a team from Olin College submitted a proposal to join the Nationwide Eclipse Ballooning Project (NEBP) [1] on the engineering track. This would be the group's first project involving high-altitude ballooning. The engineering track is a natural fit and complement to Olin's predominately hands-on project-based curriculum. Preparations began in the Spring 2023 semester after acceptance into the program. In the early fall of 2023, an engineering faculty member with a specialty in wireless communications and a student from Boston College joined the project. The following sections describe the team's activities related to the balloon launches for the 2023 annular and 2024 total solar eclipses.

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2. Annular Solar Eclipse October 2023

2.1 Preparation

In the spring semester of 2023 several students were involved with the project. Three students did Independent Studies for course credit. Two of the students focused on engineering systems integration by combining the NEBP engineering track material with study of the NASA Systems Engineering Handbook [2]. Their deliverables were power and data system diagrams and the development of an analysis process to evaluate design choices for integrating custom hardware with the standard NEBP engineering payload [3]. The third student focused on the mechanical design of a pan-tilt mechanism for a camera system. Outside of the formal course structure, two students assembled the ground station. At the end of May, one faculty mentor and two students attended the week-long regional Pod workshop. At such an early stage of the project, working with both experienced teams and those with similar entry-level experience provided a tremendous boost to the team's learning. Through the following summer (10 weeks), four students worked full time to assemble the NEBP systems, and design and fabricate custom instruments of their own design (described in the next section). They were funded by a grant from the Massachusetts Space Grant Consortium. At the end of summer, a successful ground test of the NEBP systems was performed.

2.2 Payload

The NEBP systems (Iridium tracking and control, RFD900, PTERODACTYL, and Raspberry Pi video steaming systems with the UMD vent/cut-down [4]) were placed in boxes constructed from foam insulation (1 in. thick) panels and covered with orange duct tape. The tops of the boxes were secured with nylon webbing straps. The lines connecting the boxes were tied directly to the straps.

Two of the custom instruments that were built in the summer were included in the payload. The first was a modified version of an open-source Geiger counter [5] (see Fig. 1) which consists of a Geiger-Muller tube (SBM-20) mounted on a PCB (manufactured through JLCPCB) with surface-mount components, an Arduino, and a microSD breakout board (MicroSD Breakout+, Adafruit Industries). To generate the required 400 V operating voltage, a boost-converter topology was implemented using a DC-DC switching converter and energy-storing components to step up the input voltage.

A 555-timer is used to create a high-frequency waveform controlling the gate of a switching BJT transistor. While the transistor is closed, the input voltage is applied across an inductor, and the current increases linearly. A reverse-biased diode is used to prevent current flow to the high-voltage load during this phase. While the switch is open, the built-up current can no longer flow through the transistor, so the diode becomes forward-biased and allows current to flow to the load as well as an energy-storage capacitor. A microcontroller (ATtiny2313) processes the analog data into the more-useful counts-per-minute (CPM) measurement which the Arduino saves to the microSD card every minute.

The second custom instrument consists of four single-use, 35 mm film cameras (FunSaver, Kodak) that were modified for automatic operation; see Fig. 1. The battery, flash, and viewfinder lens were removed. Each camera was mounted on a 3D-printed bracket which was in turn attached to a laser-cut base plate holding two servomotors: one to wind the film (FEETRCH FS90R) and one to trigger the shutter (MG90S). The servos and shutter switches were plugged into a custom PCB stacked on top of an Adafruit Feather 32u4 development board powered by a lithium-ion battery. The custom PCB included a real-time clock (DS3231), a 3.3V to 5V boost converter to power the servos, and headers to plug in each servo and switch. The cameras were programmed to take a picture every 10 minutes.

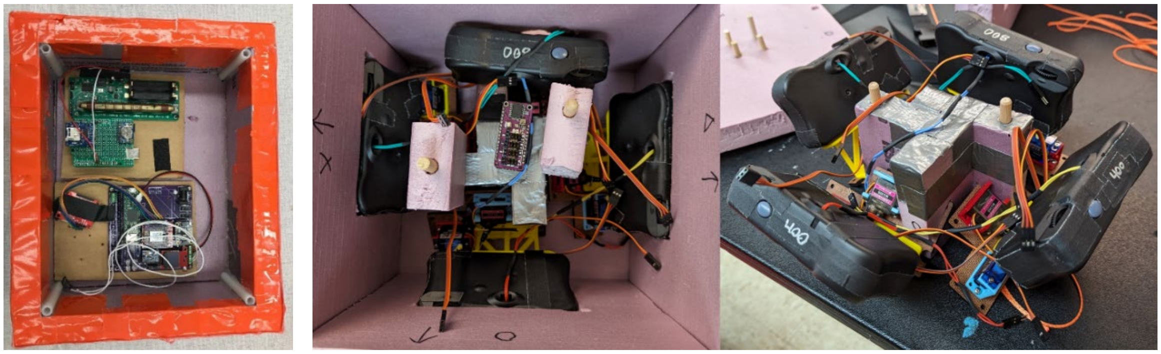

Fig. 1. Custom Geiger counter with PTERODACTYL in payload box (left). Film cameras inside (middle) and outside (right) the payload box.

2.3 Launch, Flight Path, and Recovery

For the annular eclipse, the team stayed and set up the ground station at the Texas Tech University Center at Junction, TX, along with several other NEBP teams (both engineering and atmospheric sciences). The 1600 g balloon was launched in light winds from the SW from an open field at Exit 420 off Route 10 about 40 miles west of Junction; see Fig. 2. The balloon was tracked using the ground station (see Fig. 3) and was able to stream video for a short period of time. The sky was clear, so the “ring of fire” was clearly visible from the ground; see Fig. 3. Approximately 30 min after annularity, commands were sent through the MSU Borealis server to open the vent and then cut down.

The balloon reached a maximum altitude of 76,223 ft. After a flight of 2 hrs. 55 min, it landed 108 miles away at top of Smoothing Iron Mountain (approximate elevation 500 ft); see Fig. 4. After contacting the landowner through the local Sheriff’s office to get permission to enter the property, the payload, and unexpectedly the balloon, were recovered; see Fig. 5. The cut-down circuit on the vent melted through the line holding the vent sections together but the line did not unwrap and, therefore, the balloon did not separate from the payload. Fortunately, the vent had been opened prior to sending the cut-down command. Note that all references to *descent* in the paper refer to descent under the balloon, in contrast to descent under the parachute alone.

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Fig. 2. Launch site (left). Successful launch with six payload boxes (right).

Fig. 3. Ground station at TTU Center Junction TX (left). Cell phone photo of the "ring of fire" (right).

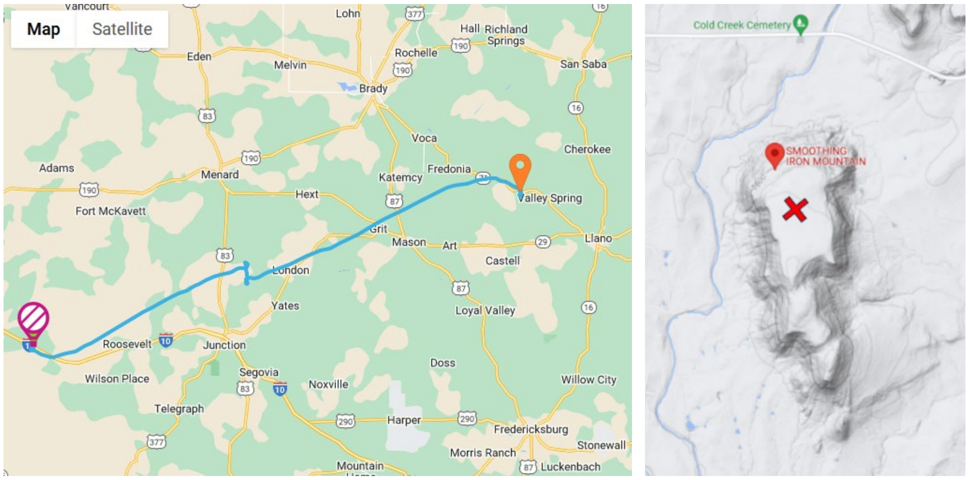

Fig. 4. Flight path (left). Launch from Exit 420 on Route 10, 40 miles west of Junction. Landed on Smoothing Iron Mountain, altitude about 500 ft (right).

Fig. 5. Payload and parachute with balloon still connected in a tree (left). The payload was recovered after a short hike (right).

2.4 Measurements

In this section, representative measurements from the PTERODACTYL are plotted with respect to altitude. Data from ascent (descent) are denoted in black (red). For reference, the altitude profile taken from the MSU Borealis Flight Tracker is presented in Fig. 6. Atmospheric pressure is also shown in Fig. 6. At maximum altitude, the pressure is 0.03 atm. The ground speed (mph) during ascent and descent are very consistent; see Fig. 7. The vertical ascent speed measurements have unexpectedly large variations, so the data was averaged in 50 sample intervals (approximately 200 ft per interval). The balloon rises at a rate of approximately 1000 ft/min as was designed. The temperature (on the PCB of the PTERODACTYL) behaves as expected, decreasing during ascent, and then increasing during descent. The box temperature is that of the air inside of the PTERADACYL's Styrofoam enclosure, so it drops to much lower temperatures. Note that during ascent in between about 54,000-25,000 ft temperature measurement were intermittent.

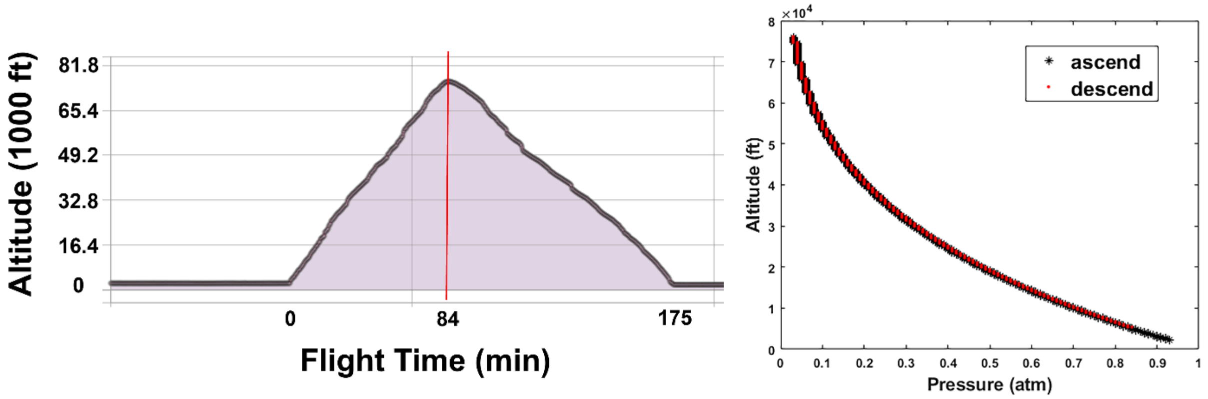

Fig. 6. Altitude profile from MSU Borealis flight tracker (left). Pressure vs. altitude from the PTERODACTYL (right). Ascend (black). Descend (red).

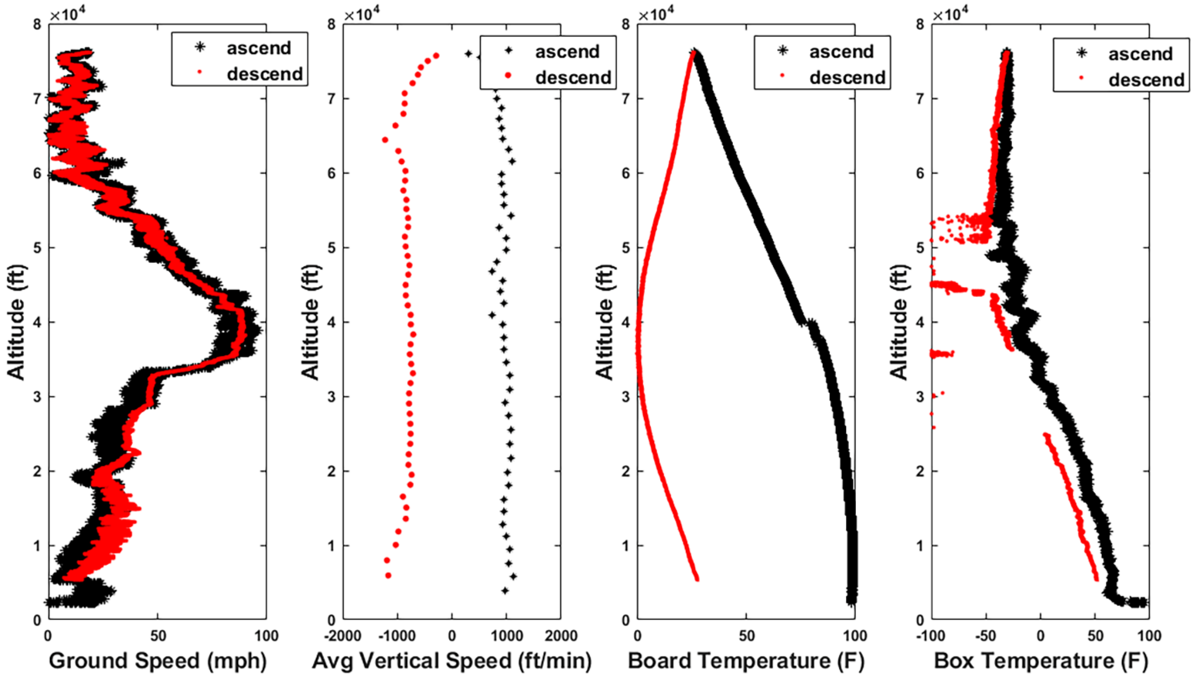

Fig. 7. Ground speed (right), vertical speed (second from right), board temperature (second from left), and temperature inside the box enclosure (left) from the PTERODACTYL. Ascend (black). Descend (red).

Fig. 8 shows the yaw, pitch and roll orientation angles of the PTERODACTYL itself. The payload appears to be constantly spinning back-and-forth during ascent and descent based on the yaw measurements. There is limited pitch and roll motion. Measurements from the Geiger counter are shown as the balloon ascends in Fig. 9. The counts per minute increase sharply beginning around 40,000 ft altitude and then reach a maximum at approximately 60,000 ft. This is the Regener-Pfotzer limit at which the cosmic radiation intensity is the highest [5]. This point occurs approximately 50 minutes before annularity with 40% eclipse magnitude. Unfortunately, data logging cut out partway through the eclipse. After recovery of the custom film camera system, it appeared that the film advanced successfully in three of the cameras. However, all the pictures were completely unexposed except for one which was blurry, possibly due to its box spinning. Fig. 10 is a screen shot taken from streamed video from the Raspberry Pi ArduCam system.

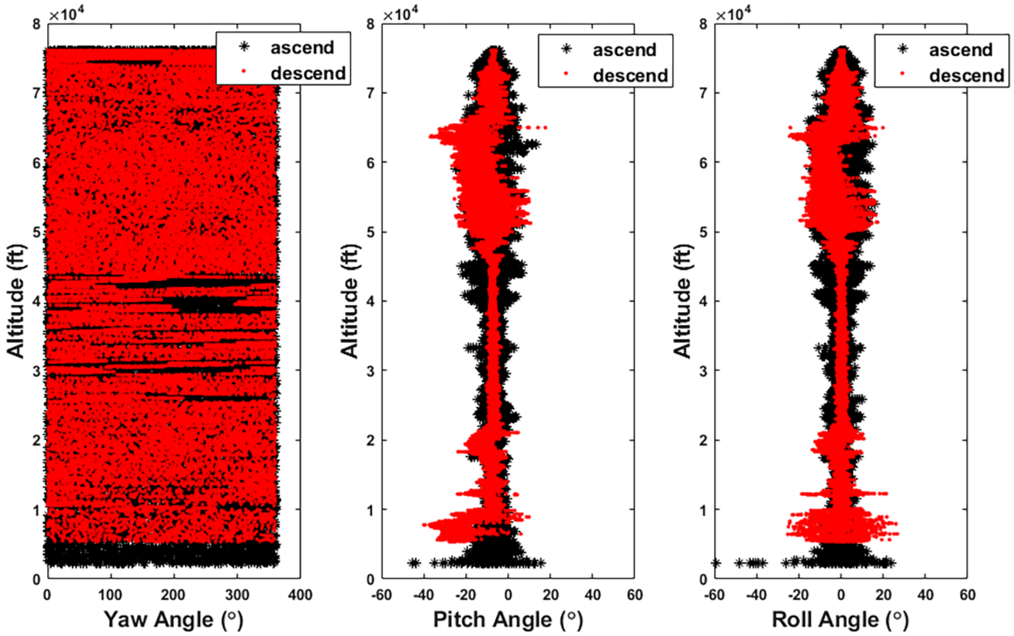

Fig. 8. Yaw (left), pitch (middle), and roll (right) measurements from PTERODACTYL. Ascend (black). Descend (red).

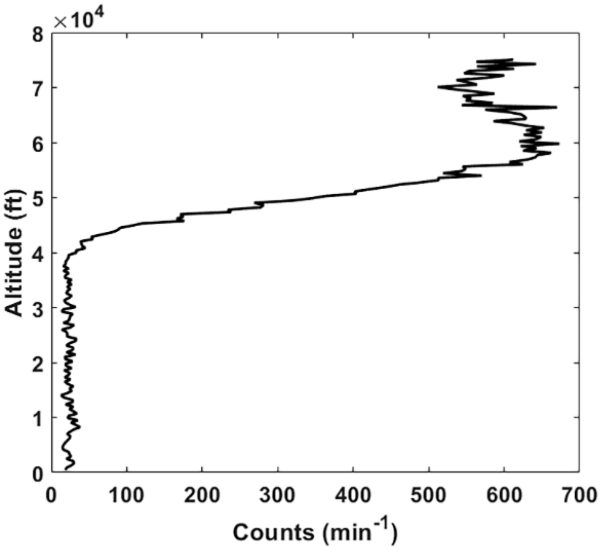

Fig. 9. Altitude vs. counts measured with custom Geiger counter instrument during ascent. The Regener-Pflotzer maximum is at approximately 60,000 ft.

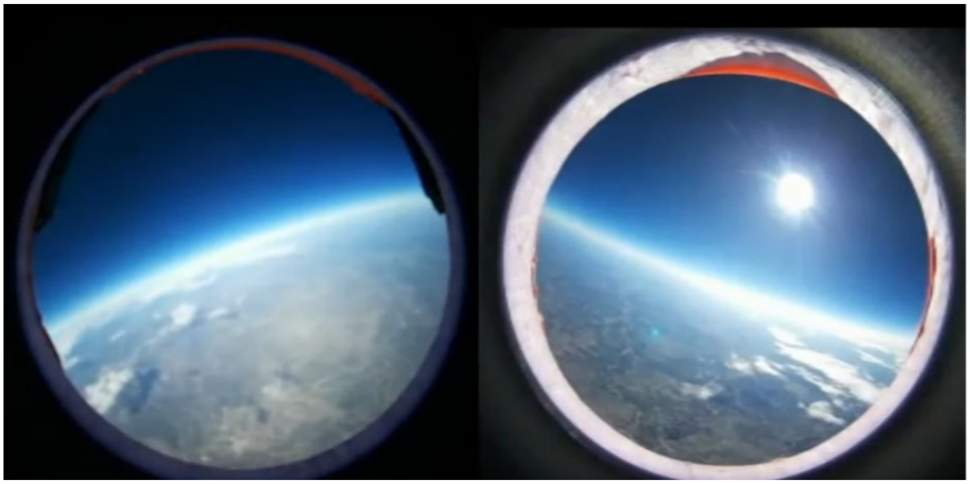

Fig. 10. Screenshot from Raspberry Pi ArduCam video cameras.

3. Total Solar Eclipse April 2024

3.1 Preparation

For the total solar eclipse, the team composition changed with four students not continuing and four new students joining the project. Based on the experience from the annular eclipse, several changes were made. The most significant was the way the payload boxes were connected. Instead of tying the boxes to straps around the boxes right before launch, a small carabiner was tied to the end each line beforehand; see Fig. 11. Now the boxes could be connected by simply and quicky clipping the carabiners together before launch. Spring cord locks were put on each line and used to keep the lids on the boxes closed. They were double looped so individual lengths of line could be adjusted for leveling the boxes.

3.2 Payload

The standard NEBP engineering package was flown again, along with the Geiger counter which was packed in the same box as the PTERODACTYL. The film camera system was not included. This time a second video streaming system based on a Raspberry Pi 4 with a 16MP Autofocus Quad-Camera Kit was added; see Fig. 11. The ground plane of this system consists of two 4 in. x 4 in. aluminum sheets as the base for the two antennas. Communication was achieved with the ground station using a modem (airMAX, Ubiquiti) powered by a battery and a PoE injector.

The ground station was constructed using a high torque pan/tilt assembly with servo motors (Torxis) controlled by an Arduino running custom code, a modem (airMAX, Ubiquiti), a 28dB dish antenna, and a tripod. The custom Arduino code was used to translate between the ground-station control software, which was designed to run the NEBP pan/tilt system, and this station, which used servo motors. The system was calibrated by measuring true angles using a digital angle gauge with the dish mounted on the servos. The pan/tilt mechanism was attached to the dish antenna using a custom, laser-cut steel attachment, with another custom, laser-cut steel plate attaching the servo motors to the tripod; see Fig. 11. In case of cloudy weather conditions where the sun is not visible, backup software can calibrate the ground station from an initial position pointing due north and flat on the ground. The design files for the custom 3D-printed and laser-cut components and software are available online [7].

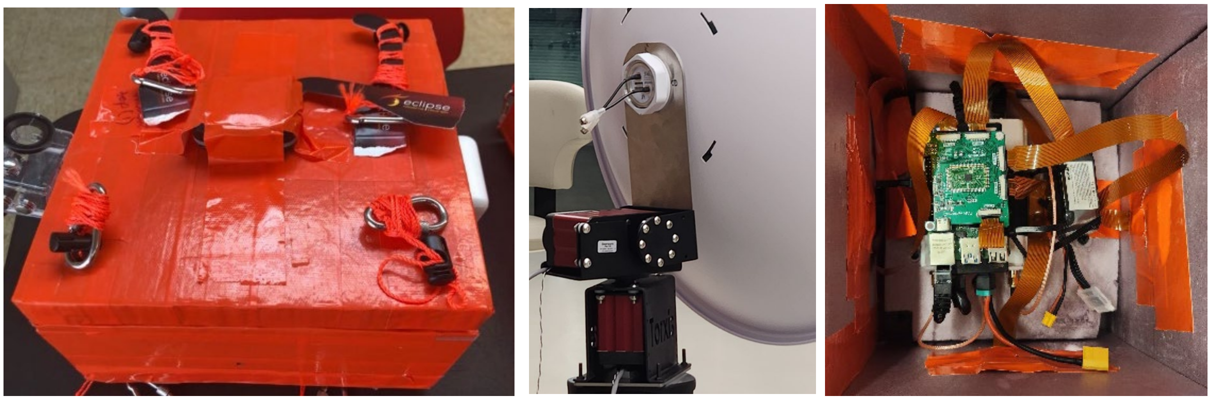

Fig. 11. Typical hardware container (left) constructed from insulation foam. Boxes are connected by carabiner clips tied at the ends of lines passing through the boxes and their covers. Spring cord locks on each line enable leveling and securing the covers. Custom pan/tilt system using servomotors (middle). Custom video streaming system (right).

3.3 Launch, Flight Path, and Recovery

For the total eclipse, the team returned to the Texas Tech Center at Junction, TX, to stay and set up the ground stations. This time the launch site was at Edwards County Airport outside Rocksprings, TX. At the first launch attempt, as the balloon was near full inflation, strong winds twisted the balloon tearing it off at the neck; see Fig. 12. Following the University of Delaware team, the second balloon was held low to the ground using the NEBP-supplied bedsheet, leading to a successful launch; see Figs.13-14.

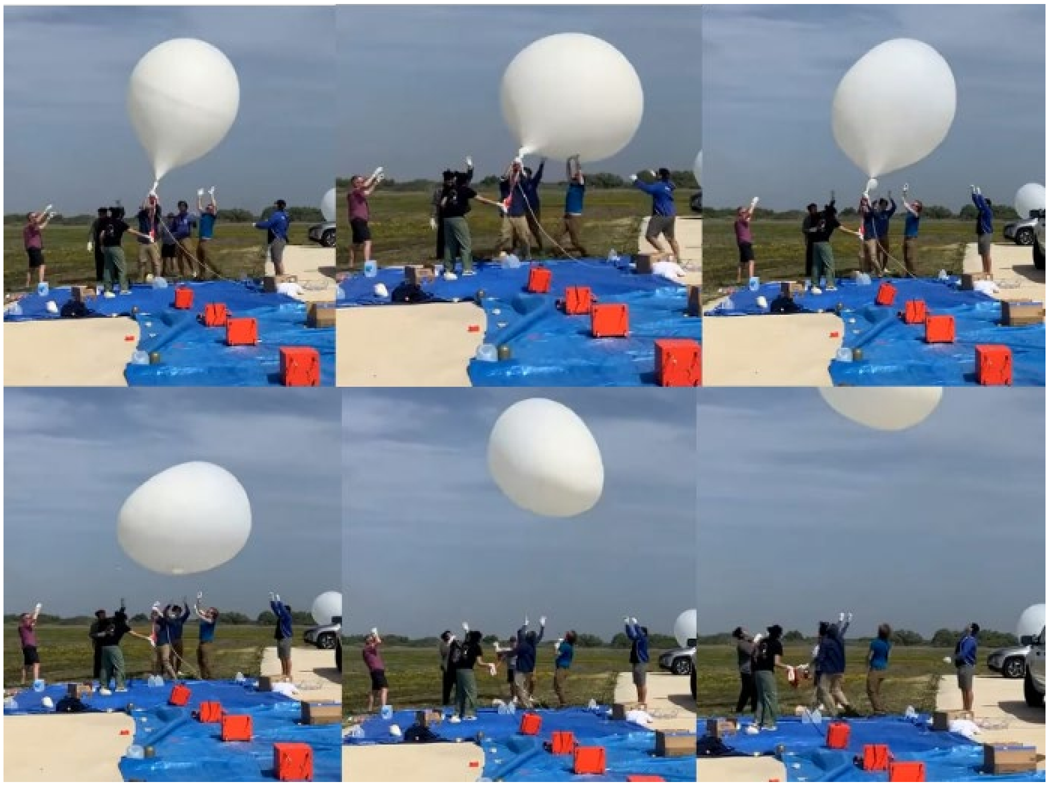

Fig. 12. First launch attempt. Strong winds twist the balloon tearing it off at the neck (starting top left).

Fig. 13. Launch of second balloon. Bedsheet used to hold balloon in place near the ground (left). Success! (right).

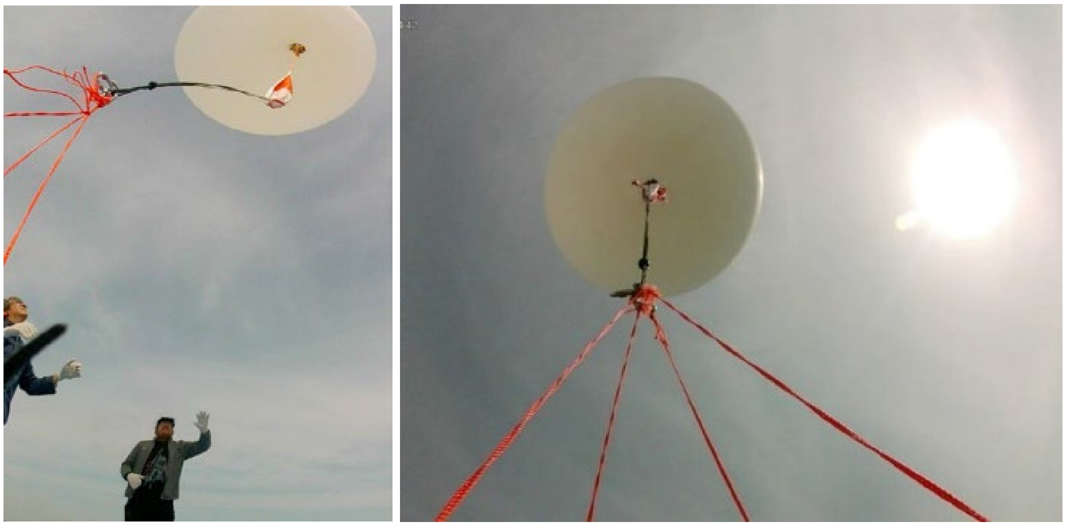

Fig. 14. Screenshots from camera mounted on the first payload box below the parachute. Just after release (left). During ascent (right).

The balloon was tracked by the ground stations at TTU Center at Junction; see Fig. 15. Since the ascending balloon was travelling laterally much faster than anticipated (*e.g.*, 130+ mph at some points) and would have flown well past the predicted landing point specified in the NOTAM that was filed, the vent was opened, and a cut-down command was sent before reaching maximum altitude. The winds brought clouds into the sky over Junction. Partial eclipses could be seen intermittently from the ground (see Fig. 15) but totality was completely obscured. The balloon reached 54,380 ft. and traveled 162 miles in 2 hrs. and 10 min. It landed in a line of trees on Fort Cavazos and was visible from the road. With assistance, the payload, parachute, and balloon (again the vent sections did not separate even though the line had melted through) were recovered; see Fig. 17.

Fig. 15. Ground station at Junction, TX (left). Cell phone photo of the sun from the ground just before totality (right).

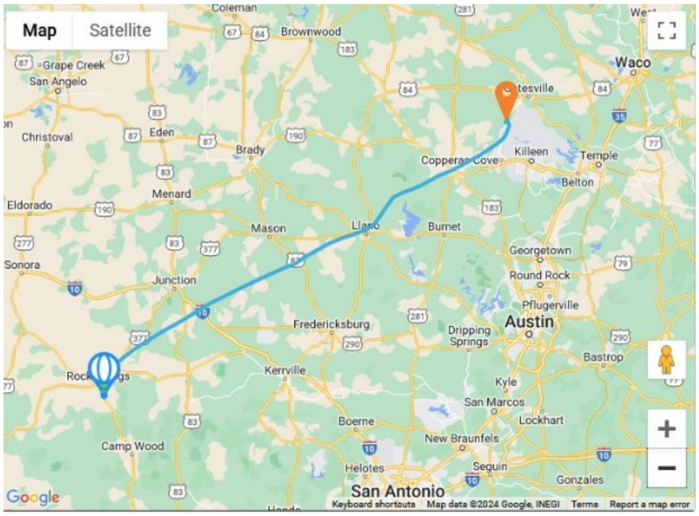

Fig. 16. Flight path. Launch from Edwards County Airport, Rocksprings TX. Landed in Fort Cavazos, TX. Distance traveled 162 miles.

Fig. 17. Balloon landed in a tree (red circle) and was visible from the road (left). Payload recovered with assistance (right).

3.4 Measurements

For comparison to measurements from the annular eclipse, representative total eclipse measurements from the PTERODACTYL are now presented. The altitude profile taken from the

MSU Borealis Flight Tracker, and the measured atmospheric pressure are shown in Fig. 18. At maximum altitude, the pressure was 0.1 atm. The ground speeds (mph) were much greater this time, in some cases over 130 mph; see Fig. 19. The vertical ascent speeds were very consistent, matching the desired rate of 1000 ft/min. The board temperature decreased uniformly during ascent, and then increased continuously during descent. The temperatures inside the box enclosure during ascent closely matched that of descent. Fig. 20 shows the yaw, pitch and roll orientation angles of the PTERODACTYL. The payload again spins (yaws) during ascent and descent. This rotation can be seen in the recorded launch video corresponding to Fig. 14. There is little pitch and roll during ascent and a limited amount during descent. Video from the NEBP video camera system was stored on the SD card but did not stream to the ground station. However, some video from the custom four-video-camera system was livestreamed. An example screen grab is shown in Fig. 21.

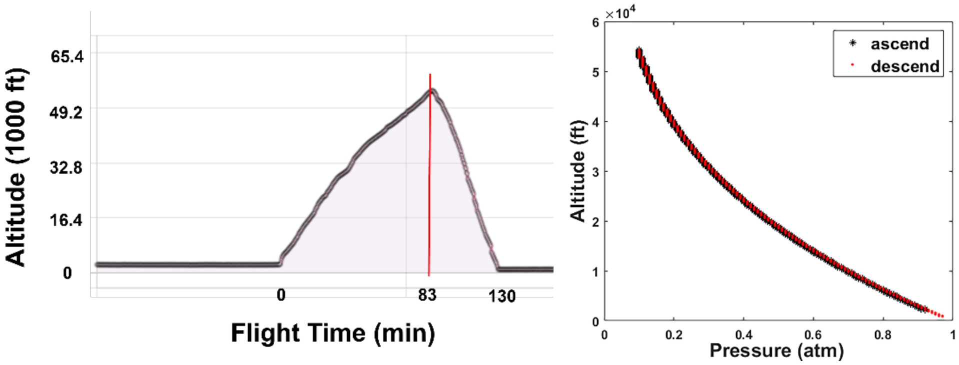

Fig. 18. Altitude profile from MSU Borealis flight tracker (left). Pressure vs. altitude from the PTERODACTYL (right). Ascend (black). Descend (red).

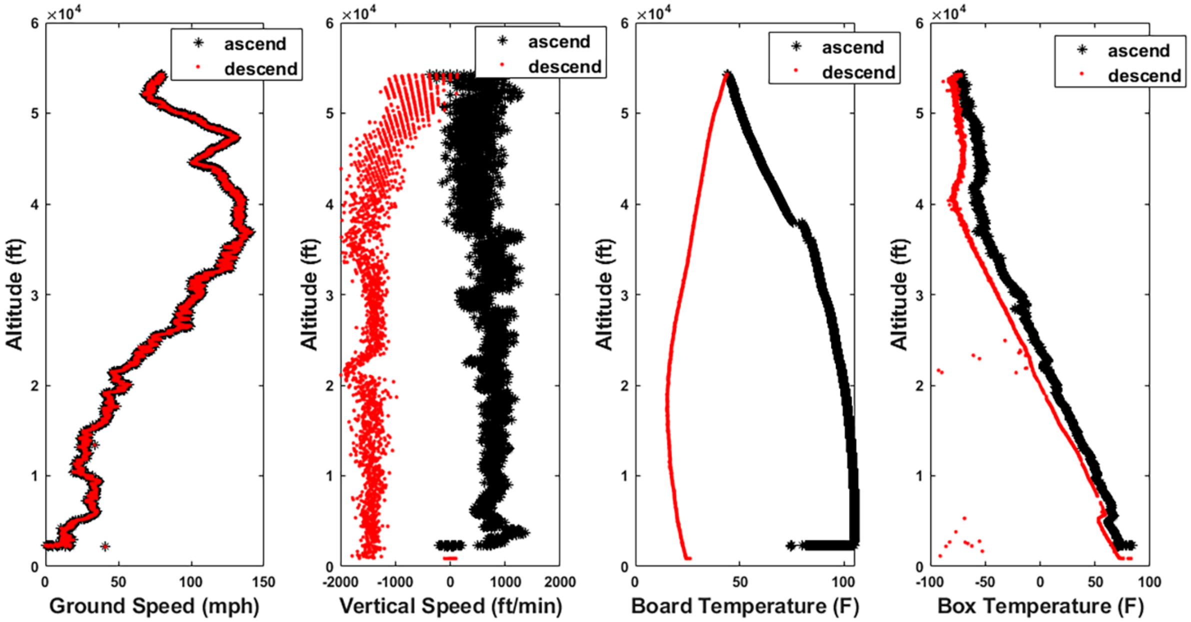

Fig. 19. Ground speed (right), vertical speed (second from right), board temperature (second from left), and temperature inside the box enclosure (left) from the PTERODACTYL. Ascend (black). Descend (red).

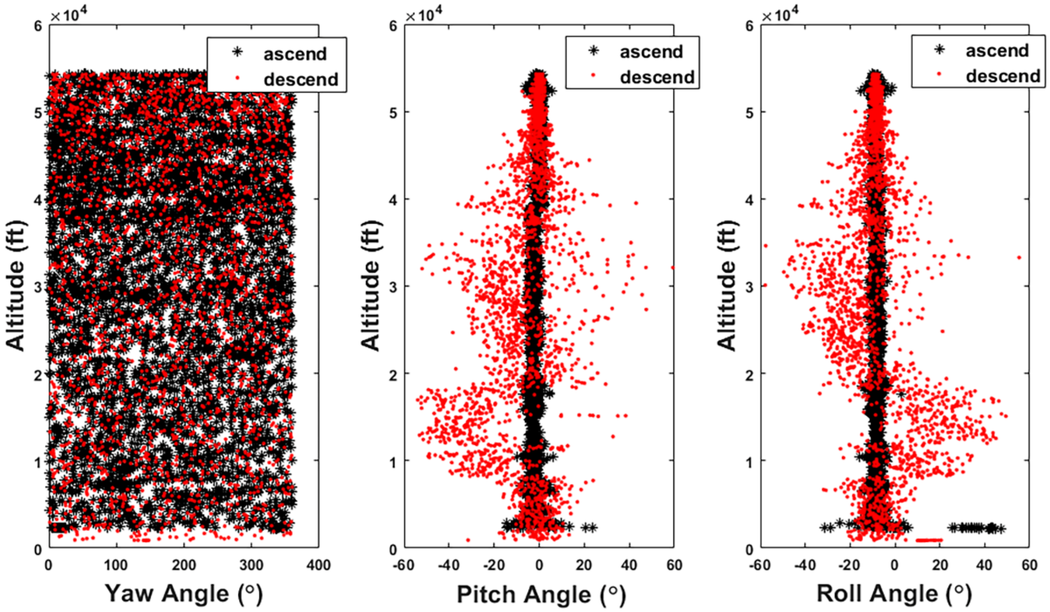

Fig. 20. Yaw (left), pitch (middle), and roll (right) measurements from PTERODACTYL. Ascend (black). Descend (red).

Fig. 21. Simultaneous screen grab from the custom Raspberry Pi ArduCam four video camera system during the livestream.

4. Conclusion and Future Work

Participation in the Nationwide Eclipse Ballooning Project was a tremendously engaging and rewarding experience for the team. The students were able to put the knowledge and skills they are learning in the classroom directly into practice and see almost immediately the outcomes of their work. The team is excited to continue high-altitude ballooning and is even thinking about how to manage launching a balloon in Spain for the next total solar eclipse in 2026. In the immediate future, work will continue with further analysis of the recorded data and to improve the reliability of the video streaming and stand-alone camera systems.

Acknowledgments

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