

# Observing the 2017 Total Solar Eclipse in the skies above Central Missouri, USA

B. Ross Carroll\* and J. Tillman Kennon<sup>†</sup> and Patrick Tribbett<sup>‡</sup>  
*Arkansas State University, Jonesboro, Arkansas 72401*

Ed Roberts<sup>§</sup>  
*Pottsville High School, Pottsville, Arkansas 72858*

We report the work and findings of Arkansas BalloonSAT in participating in the 2017 Eclipse Ballooning Project. Arkansas BalloonSAT was the site-team for Missouri and launched a high altitude balloon from Fulton High School in Fulton, MO an hour prior to totality. The eclipse balloon flight (ABS-50) marked the 50th mission of Arkansas BalloonSAT and the culmination of nearly 10 years of scientific research and science outreach (e.g., Kennon, et al. [1]). The ABS-50 balloon reached an apogee of 24 kilometers shortly after floating for one minute in the moon's umbra. In addition to live-streaming video from one payload as part of the Eclipse Ballooning Project, our mission included carrying a scientific payload and educational outreach. This report will summarize those efforts and include an examination of balloon kinematics with the cooling effect of the moon's umbra and aircraft-balloon interaction. We further discuss developments in the system to minimize payload size for future eclipse studies. Upon recovery, we note a considerable difference between actual and projected balloon paths that mark the influence of the Moon's shadow on Earth's atmosphere.

## I. Introduction

ARKANSAS BalloonSAT participated as the Missouri site team in the 2017 Eclipse Ballooning Project sponsored by Montana State University [2]. This nation-wide project facilitated dozens of University and High School teams taking images and video of the 2017 Total Solar Eclipse from the stratosphere on high altitude balloons. Arkansas BalloonSAT launched a 5.4 kg payload train on a 1.6 kg latex balloon with a series of positional tracking instruments, video and still image payloads, a scientific payload, a custom-designed spherical panoramic camera. In addition to launching this balloon from Fulton High School in Fulton, Missouri, a large eclipse viewing was held at their football stadium where participants had the chance to engage with Arkansas BalloonSAT as well as demonstration solar telescopes facilitated by students from the University of Arkansas Center for Space and Planetary Sciences.

## II. Mission Design

The ABS-50 mission consisted of a payload train with seven individual payloads and a total mass of 5.4 kg. The top-most payloads were all slightly modified versions of the Eclipse Ballooning Project's common payload kit while the bottom three payloads were from Arkansas BalloonSAT and University of Central Arkansas. Between the balloon and parachute was a cut-down module that consisted of a wirelessly activated continuous rotation servo that was mounted to a 3D printed frame with a thin line passing through its body.

Immediately below the parachute was an Iridium satellite modem designed to transmit GPS coordinates every 10 seconds as well as relay commands to the cut-down module via a 2.4 GHz XBee radio. This payload was preceded by the video and still image payloads. Both payloads were similar in construction but the video system focused on live streaming HD video while the still image system took higher quality still images at a much lower rate. Both imaging payloads made use of the Raspberry Pi single board computer and Raspberry Pi camera. The video system transmitted data down to the ground station antenna at Fulton High School via a 5.8 GHz Ubiquiti modem and the still image system relayed images via a 900 MHz packet radio.

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\*Associate Professor of Physics, Department of Chemistry & Physics, P.O. Box 419, State University, AR 72467

<sup>†</sup>Professor of Science Education, Department of Chemistry & Physics, P.O. Box 419, State University, AR 72467

<sup>‡</sup>Department of Chemistry & Physics, P.O. Box 419, State University, AR 72467

<sup>§</sup>Secondary Science Teacher, Pottsville High School, 7000 Hwy 247, Pottsville, AR 72858

These Eclipse Ballooning Project payloads were preceded by a scientific payload designed by Dr. Will Slaton and his students at University of Central Arkansas. Slaton and his team had five of these identical payloads flown during the 2017 total solar eclipse. Below this payload was a custom designed spherical panoramic camera consisting of 6 GoPro Session cameras facing outwards from a 3D printed frame. The panoramic payload also had a GPS module and orientation meter to measure position and orientation of the camera array in order to better stabilize video in post-processing.

### III. Results and Discussion

ABS-50 was launched at 17:14 UTC from the Fulton High School football stadium. It ascended at an average rate of  $6\text{ m/s}$  until burst at an altitude of  $24\text{ km}$ . The ascent rate was as expected based on the planned launch parameters except at an altitude of  $14\text{ km}$  when the wake from a jet fly-over disturbed the balloon flight. Based on video from a GoPro camera pointed up towards the balloon, this jet was above  $14\text{ km}$  and most likely one of the WB-57F NASA eclipse chase planes flying at approximately  $15\text{ km}$  towards the point of greatest eclipse. After this brief encounter that shook the dangling payloads around, ABS-50 continued its ascent until burst at  $24\text{ km}$ —about  $5\text{ km}$  short of our planned burst. Balloon burst occurred at 18:20 UTC south of Montgomery City, MO which was 4 minutes after C3, so the balloon experienced all of totality prior to burst. After burst, the payloads descended for 32 until landing in a tree limb over a small creek outside of Truxton, MO. Line-of-sight distance between launch and landing of ABS-50 was  $78\text{ km}$ . Figure 1 shows a color image taken from the Eclipse Ballooning Project video payload's Raspberry Pi camera during totality.

Although this 50th mission of Arkansas BalloonSAT was planned and executed with the expertise Kennon and Roberts have acquired since inception in 2007, one factor that greatly affected this mission was entirely unpredictable: wind changes due to the atmospheric cooling effect of the eclipse. The influence of the penumbra and umbra cooling the atmosphere has been a topic of some inquiry (e.g., Gray & Harrison[3]), however there is currently no means of predicting how this might affect balloon flights. ABS-50 was predicted to land  $30 - 40\text{ km}$  ENE of Fulton, MO but it touched down  $78\text{ km}$  in the same general direction. The GFS wind speed models used in these predictions, understandably, do not account for these so-called "eclipse winds." A more detailed examination of eclipse winds from the 2017 TSE will require an analysis of numerous actual and predicted balloon paths from several Eclipse Ballooning Project teams. Future work here will examine predicted flights based on NWS sounding balloons launched the morning of August 21, 2017.

For ABS-50, the primary differences between the actual balloon path and the predictions prior to launch are that the wind speeds in the troposphere were greater than predicted and the winds speeds in the stratosphere diminished. Comparing the paths in Figure 2, we see that the total distance between launch and landing was nearly double that of our predictions with a general increase in wind speeds in an east-northeasterly direction.

Figure 4 compares the balloon's lateral speed as a function of altitude for ascent and descent. There is little deviation between the two sets of data. This indicates that wind speeds did not change dramatically during the flight. The launch occurred at 30 minutes after First Contact (C1) and approximately one hour prior to totality. Landing was 50 minutes prior to Fourth Contact (C4).

### IV. Conclusion

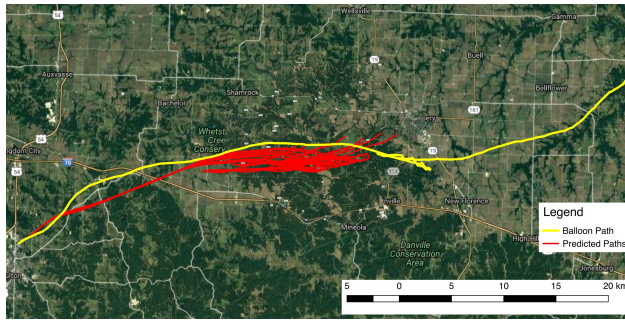
This mission was a milestone for Arkansas BalloonSAT and a opportunity for edge-of-space sciences during a rare astronomic event. The collective work of the Eclipse Ballooning Project, Arkansas BalloonSAT, and event participants resulted in an impactful experience for several hundred high school students in Central Missouri as well as providing a unique look at eclipse-affected winds. Future work will focus on a survey of balloon flight paths to determine altitude-dependent eclipse winds and additional balloon flights for upcoming total solar eclipses.

### Acknowledgments

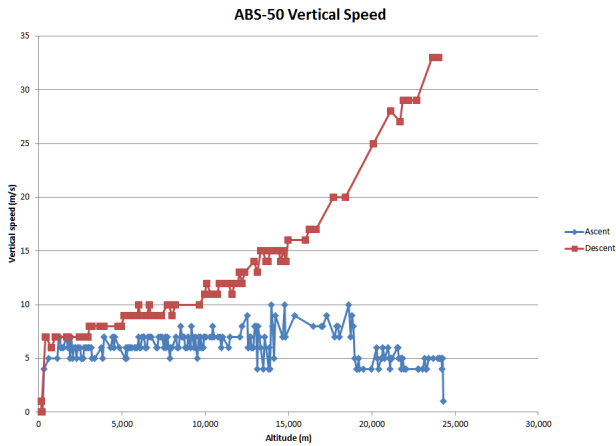
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**Fig. 1** Color photograph of the Moon’s umbra over Fulton, MO taken at an altitude of 23 km with a Raspberry Pi camera.



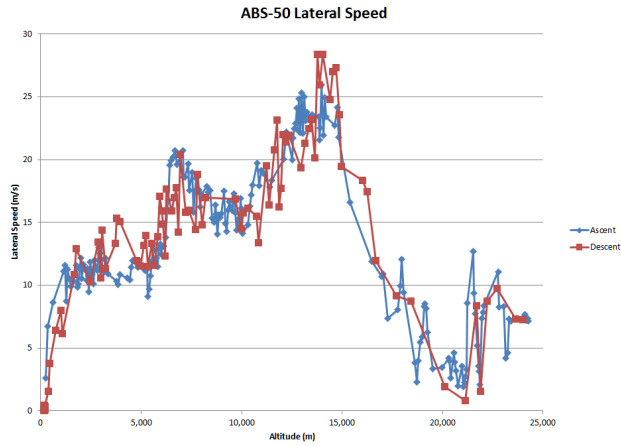
**Fig. 2** Flight path of ABS-50 and a set of ten simulated flight paths determined using GSF windspeed data from prior to launch.



**Fig. 3** Vertical speed vs. altitude on ascent (blue circles) and descent (red squares) of ABS-50 taken from Iridium modem data.

### References

[1] Kennon, J. T., and Fong, B., “Integrating K12 Outreach with Undergraduate & Graduate Student Research through BalloonSAT: High Altitude Balloons,” 2015.



**Fig. 4 Lateral speed vs. altitude of ABS-50 on ascent (blue circles) and descent (red squares) showing consistent wind speeds throughout flight.**

- [2] Colman Des Jardins, A., Berk Knighton, W., Larimer, R., Mayer-Gawlik, S., Fowler, J., Harmon, C., Koehler, C., Guzik, G., Flaten, J., Nolby, C., Granger, D., and Stewart, M., "Nationwide Eclipse Ballooning Project," *AAS/Solar Physics Division Meeting*, AAS/Solar Physics Division Meeting, Vol. 47, 2016, p. 105.01.
- [3] Gray, S. L., and Harrison, R. G., "Eclipse-induced wind changes over the British Isles on the 20 March 2015," *Philosophical Transactions of the Royal Society of London Series A*, Vol. 374, 2016, 20150224. doi:10.1098/rsta.2015.0224.