Project CODENAME

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Part I

Introduction

High Altitude Challenge

This document is an overview of a design concept submitted to the 4th Annual High Altitude Challenge at Stevens High School. The competition has challenged over 30 teams to submit grant proposals for high altitude balloon payloads. Selected payloads would be attached to helium-filled weather balloons and lifted into the atmosphere, to a projected height of over 120,000ft. The payloads would then have to return to the ground safely (with the help of a parachute.) The exact function of the payload was left up to individual teams, but general guidelines included taking sensor readings of the atmosphere and/or aerial photographs.

The ultimate goal of the High Altitude Challenge is to launch a student-built satellite: a payload that will orbit earth and transmit data back to a ground station in South Dakota. Each year's winning teams build upon the work of previous teams, using high-altitude balloons to put payloads into conditions that most nearly represent what will be experienced by a satellite and collecting information to make the next year's payload lighter, more efficient, and closer to that of a satellite.

With this in mind, the primary goal of Project CODENAME was to research the demands placed on equipment that might be used for a similarly sized payload placed on a satellite and sent into orbit around Earth. Much of the data collected revolved around assessing conditions within the payload itself and analyzing the effects of the ambient environment on the performance of computing components.

The more specific guidelines put in place for this year's competition are described below:

The payload is required to:

1. Adhere to all federal, state, and local laws and comply with FCC and FAA regulations.
2. Communicate with the ground at all times via APRS radio.
3. Include a redundant means of locating the payload on the ground, should the primary method fail.
4. Return photographic evidence of the entire flight, including the balloon burst.
5. Measure external temperature and pressure AND monitor internal temperature and pressure at all times during the flight.
6. Be able to survive 10-g accelerations in every orientation.
7. Be reusable.
8. Measure 3-axis acceleration.
9. Weigh LESS THAN 250 grams (including parachute and lines).
10. Minimize instabilities (specifically spinning).

Team CODENAME won first place in the competition and was awarded a $3,000 grant to build the payload described in this document. The payload was launched on May 21, 2017 and recovered within an hour of landing.

Team members included: Joshua Morin-Baxter and Alan Zhu (Project Leaders), Nathan Wiley, Karah Haug, Maia Zoller, Paige Gehlsen, Parker Guernsey, Grace Hoffmann, Carter Meyer, Josh Christensen, James Bradford, Tristan Christoffer, Calvin Nefsger, Alex Robin, and Kathlynn Short.

Extensions to Project ECLIPSE

Much of Project CODENAME was reused in a subsequent launch to photograph the Great American Solar Eclipse on August 21, 2017. The reuse of equipment allowed for the development of important conclusions about questions raised by the results of the Project CODENAME launch. At the end of each part in this report, there is a section labeled "Extensions to Project ECLIPSE." In these sections, we will develop the details of the second launch, highlighting the important parts of the payload that were not the same.

Team members included: Joshua Morin-Baxter, Alan Zhu, Nathan Wiley, Isaiah Morin-Baxter, Annie Schleusener, Hannah Brown, Marita Schmitz, Gabriel Spahn, Taylor Wolff, and Alexa Morin-Baxter.

Special Thanks

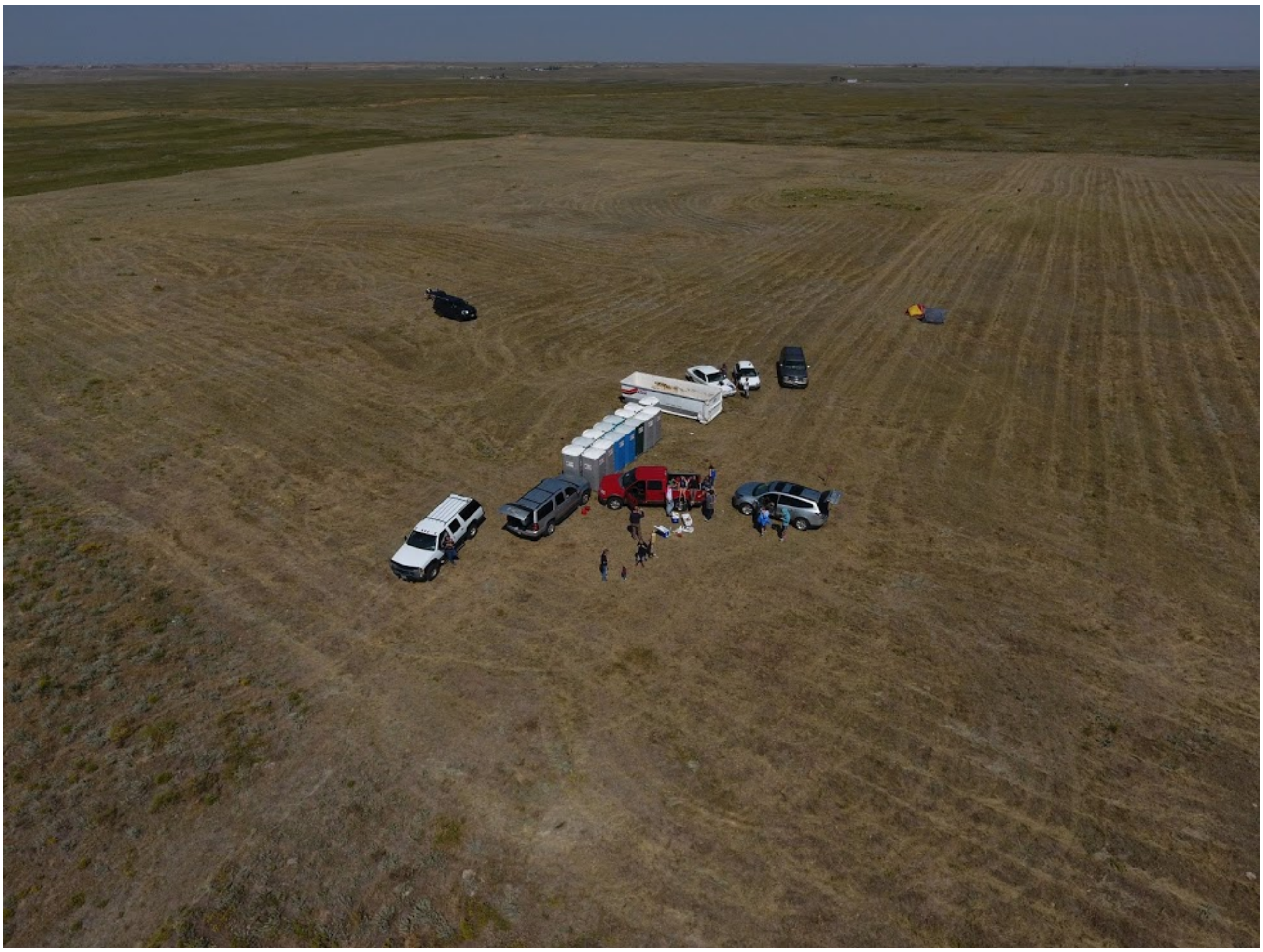
Project CODENAME's recovery team with their payload where it landed after its 9-hour flight.

Project CODENAME and Project ECLIPSE would like to thank:

- **A&B Welding,** for the generous donation of the helium required to get Project CODENAME off the ground AND for another, equally generous donation to Project ECLIPSE.
- **Dr. Andrew Smith,** for putting together the High Altitude Challenge and securing funding for winning teams, as well as acting as a sounding board for ideas throughout Project CODENAME; additionally, for loaning Project ECLIPSE a balloon and other equipment.
- **Dr. Guodong Wang,** for providing ideas and information throughout the project, and providing specific support in securing a camera extension cord for the chipset (even going so far as to call Chinese manufacturers on our behalf).
- **Michael Bales** at Tracksoar, for helping us through numerous Tracksoar-related issues and going out of his way to accommodate the highly time-sensitive nature of the project.
- **Brian Baxter and Tammie Morin,** for giving both Project CODENAME and Project ECLIPSE a place to develop their payload, despite the immense amount of time and ridiculously late hours necessary, and for providing food for team members during those meetings. Additionally for providing transportation and significant support of every kind before, during, and after the ECLIPSE launch. Their generosity on every conceivable front made these projects possible.
- **Penny Zabel,** for the design of her bufkit weather data collector program, the basis for the GOSH flight predictor.
- **Mr. Penfield** at SoundPro, for his invaluable insights into the camera extension cord and assistance with chipset disassembly.

Project ECLIPSE would also like to thank:

- **Anthony Laffitte and Family,** for providing the perfect last-minute place to launch Project ECLIPSE, and volunteering to help stabilize the balloon during highly critical pre-launch operations.
- **Mrs. Weisbeck and Family, Lusk, WY,** for providing a place to stay and finish last minute launch preparations; additionally, for providing a place to stay during the search for the payload (in a region where hotel rooms ran about $900 a night thanks to the eclipse).
- **Terry Stevenson,** for acting on behalf of Project ECLIPSE to find a place to launch in Wheatland, WY.
- **Gene and Jackie Sandersfeld** of the Mill Iron Bar Ranch, who not only graciously allowed the recovery team to retrieve the fallen payload from their ranch but helped in the recovery effort itself.



Project ECLIPSE waiting for totality after launch. (Photo taken by a Phantom 4 Drone piloted by Isaiah Morin-Baxter.)

Part II

Path Prediction, Tracking, and Recovery

Flight Path Prediction

The target landing area for the payload was Badlands National Park. Project CODENAME utilized a two-part method for predicting the path of the balloon. Following the opening of the launch window on April 1, possible flight paths were run via the HabHub Predictive Engine[1] on a weekly basis in search of a flight path that looked promising. See Figure 1 for an example of this. If a given date looked promising, CODENAME moved to the more accurate GOSH Flight Path Predictor (which can only predict three days into the future). This program was created through the collaborative efforts of Gabriel Spahn and Joshua Morin-Baxter, based on work done by Penny Zabel. The GOSH Flight Path Predictor allows for an hour-by-hour analysis of every possible flight path within a three day window. See Figure 2 for a better idea of what this means. The GOSH Flight predictor program is available on Project CODENAME's GitHub.

Both flight path predictors rely on the following information to provide accurate predictions.

Launch Point (lat long) 44.05517, -103.2035 (Robbinsdale Park)

This location was selected to provide the most direct connection between the Tracksoar APRS Tracking device used to report GPS position and the nearest APRS relay station.

Launch Point Elevation 1043.2 m or 3422.5 feet

This elevation was provided by the Tracksoar APRS tracking device during tests at Robbinsdale Park, and is consistent with the average elevation of the Black Hills.

Burst Altitude 39060m

Determined by factors such as helium volume, balloon size, positive lift, and parachute size. See Part IV for a discussion of these items.

Ascent Rate $3.83\frac{\mathrm{m}}{\mathrm{s}}$

Determined by factors such as helium volume, balloon size, positive lift, and parachute size. See Part IV for a discussion of these items.

Descent Rate $4.5658\frac{\mathrm{m}}{\mathrm{s}}$

Determined by factors such as helium volume, balloon size, positive lift, and parachute size. See Part IV for a discussion of these items.

Project CODENAME launched on May 21, 2017 at 6:00 AM. Predictions indicated that the payload would land near the southwest corner of the Badlands National Park after flying for approximately 5 hours.

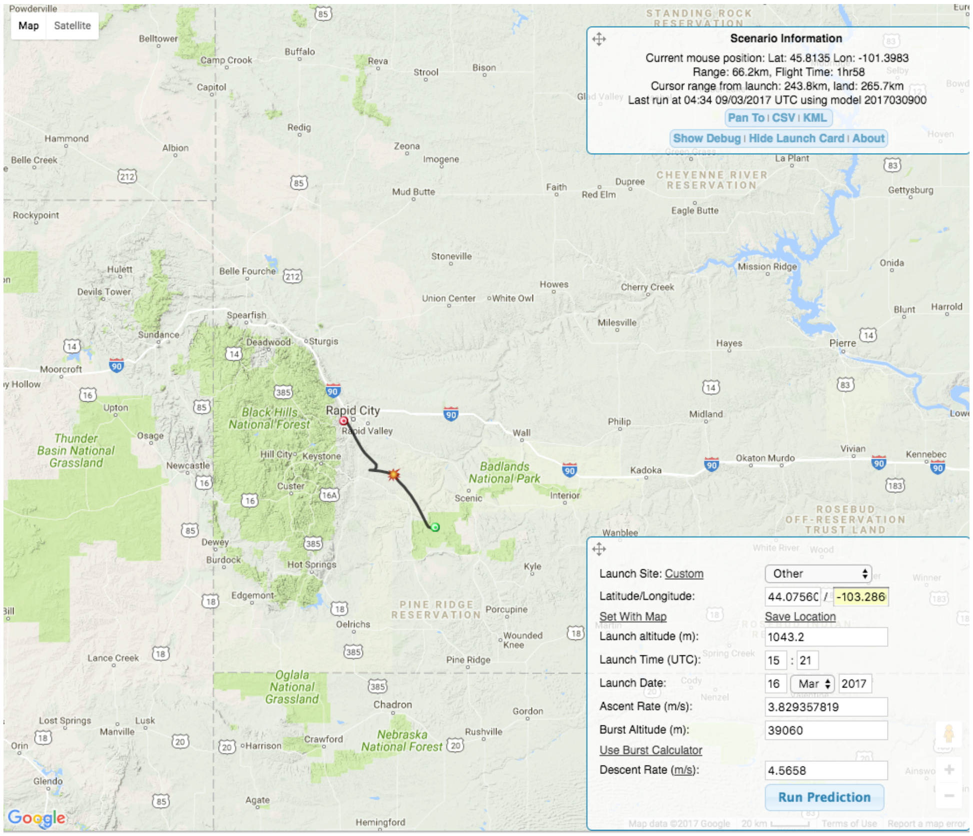


Figure 1: Example HabHub flight path prediction map for March 18, 2017.

Launch Details			An explanation of each input field is provided in the README section	Payload Details		keep the Bufkit Data Collector file open while using this workbook	Run
Month	*Day*	*Year*		gas (cubic liters)	1699.01		
3	29	17		mass (kg)	2.300		
Launch Point	44.075604	-103.286696		drag coefficient	0.5		
Target Point 1	43.973828	-102.332969		burst altitude (m)	32613		
Target Point 2	43.647654	-102.763701		descent velocity (m/s)	3		
				Launch elevation(m)	1044		

Time			Absolute Location			Relative Distances (Miles)		
Launch Time	**Full Date**	**Flight Time (hr)**	**Coordinates**		**View Map**	**From Target 1**	**From Target 2**	**From Launch**
03/29 at 03:00	170329/0300	3.707544339	43.91697177	-102.5415056	Google Maps	11.093	21.659	38.62691475
03/29 at 04:00	170329/0400	3.728016717	43.89405507	-102.4943859	Google Maps	9.741	21.688	41.33803453
03/29 at 05:00	170329/0500	3.749492665	43.88574618	-102.5058813	Google Maps	10.539	20.883	40.97660784
03/29 at 06:00	170329/0600	3.768404416	43.92879826	-102.4069994	Google Maps	4.821	26.342	44.88163954
03/29 at 07:00	170329/0700	3.780559709	43.91296307	-102.304696	Google Maps	4.434	29.331	50.08813029
03/29 at 08:00	170329/0800	3.788840826	43.93671101	-102.1898203	Google Maps	7.568	34.901	55.34862102
03/29 at 09:00	170329/0900	3.793380912	43.92689667	-102.001841	Google Maps	16.787	42.618	64.67856236
03/29 at 10:00	170329/1000	3.799620592	43.8834138	-101.8457591	Google Maps	25.036	48.613	72.86079466
03/29 at 11:00	170329/1100	3.813001227	43.83023927	-101.7556304	Google Maps	30.406	51.879	78.01955155
03/29 at 12:00	170329/1200	3.820695442	43.83201266	-101.7064875	Google Maps	32.691	54.290	80.38031444
03/29 at 13:00	170329/1300	3.826514448	43.87486423	-101.7414928	Google Maps	30.218	53.370	78.0716801
03/29 at 14:00	170329/1400	3.813113885	43.91119403	-101.7933084	Google Maps	27.194	51.720	75.09500261
03/29 at 15:00	170329/1500	3.792599368	43.95599689	-101.8416889	Google Maps	24.463	50.674	72.27304213
03/29 at 16:00	170329/1600	3.765995825	44.01608122	-101.9362534	Google Maps	19.934	48.465	67.19244421
03/29 at 17:00	170329/1700	3.739001468	44.09211327	-102.0113398	Google Maps	17.946	48.450	63.30717917
03/29 at 18:00	170329/1800	3.717245331	44.16993916	-102.0610007	Google Maps	19.128	50.257	61.14060449

Figure 2: Example prediction using the GOSH Flight Path Predictor.

Tracking

The CODENAME payload provided its precise GPS location at 30 second intervals, transmitted by the Tracksoar APRS tracking device (discussed further in Part III, Section III). This real-time location data was accessible at `http://aprs.fi`, allowing for constant monitoring of the flight. Project CODENAME followed the payload from the ground, with the goal of being the first team to see their payload land. Unfortunately, due to unpredictable weather and atmospheric conditions, the balloon became trapped at high altitude above mid-western SD for several hours, turning the 5 hour flight into a 9 hour endeavor. Project CODENAME became the first HAC team to wait over an hour in a Subway restaurant for their balloon to land, and got within one mile of seeing their payload land.

Since the Tracksoar APRS tracking device requires line-of-sight communication with ground-based APRS relay stations, Project CODENAME brought a handheld APRS radio and antenna in the hopes of collecting extra data points transmitted after the Tracksoar descended out of sight of relay stations. While this tool did not work as expected, it has important implications for future tracking strategies. This is because a satellite launch will most likely rely on line-of-sight communications with a ground station, as no comprehensive system comparable to the APRS relay network exists for space launches. Additionally, APRS is not designed to transmit photographs or video in real-time, which will be an important requirement for a space launch that does not return its payload to earth.

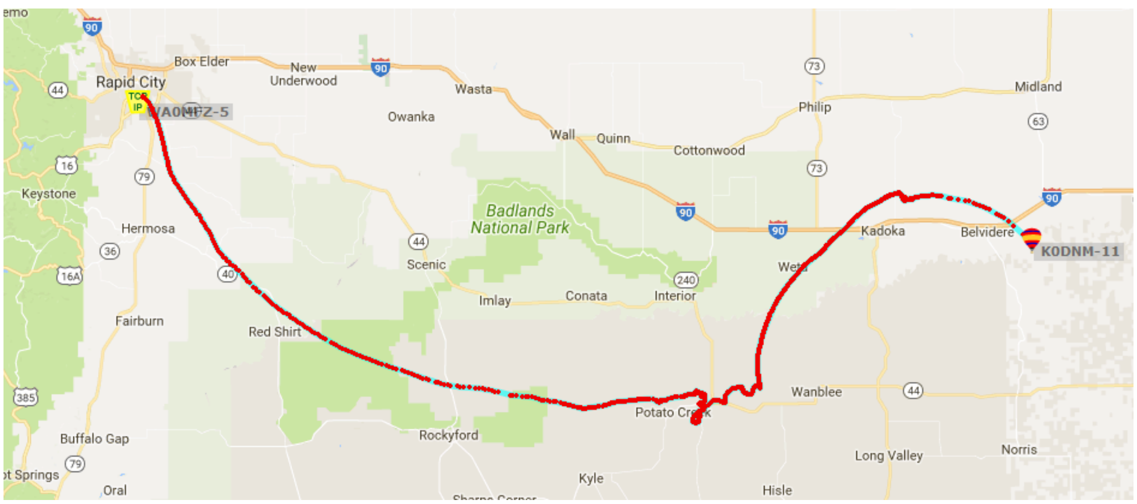


Figure 3: Map of the overall path of the payload (callsign K0DNM-11) during flight, from aprs.fi.

Project CODENAME trying to establish contact with their payload after one of their cars broke down.

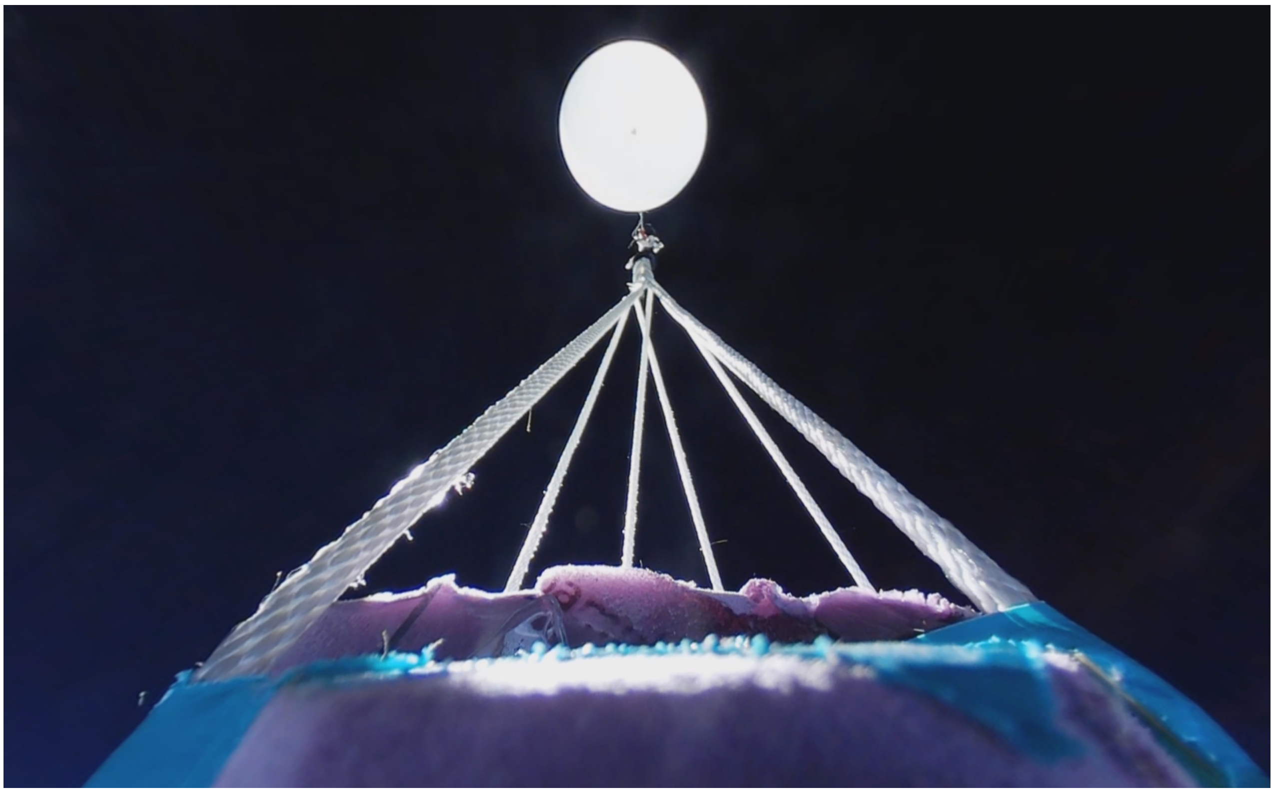
Recovery

The payload was recovered on Pine Ridge Indian Reservation Trust Land within an hour of landing, having overshot its predicted landing position due to the unexpected atmospheric conditions that extended the flight time by nearly four hours. It was found in the middle of a large grassy field within an hour of landing, approximately two miles from the nearest road. Project CODENAME searched the area on foot as well as with a Phantom 4 Drone. The payload and its internal components were discovered almost entirely intact, suffering only a few minor cracks in the outer shell despite the failure of the parachute to fully deploy. All collected sensor data was discovered intact and properly recorded, along with nearly 350 high-quality photographs.

Project CODENAME hiking back with payload and balloon in tow, along with the drone used for aerial reconnaissance.

Extensions to Project ECLIPSE

Project ECLIPSE used many of the same predictive tools as detailed in the previous section; however, given the nature of the eclipse, there was a very narrow range of options when it came to time and launch locations that would allow adequate photography of it. The GOSH Flight Path Predictor was used to determine a launch location and helium volume that was guaranteed to take the balloon through the path of totality. Unfortunately, due to unforeseen complications with fill volume measurement equipment and windy ground conditions, the first balloon launched by Project ECLIPSE came crashing back to earth. A second balloon was launched, but as it no longer matched the flight-path predictions it did not travel directly through the path of totality. However, the launch still successfully captured an incredible selection of interesting photographs of the eclipse and of Midwestern America from the air.



Photograph taken by Project ECLIPSE at approximately 100,000ft.

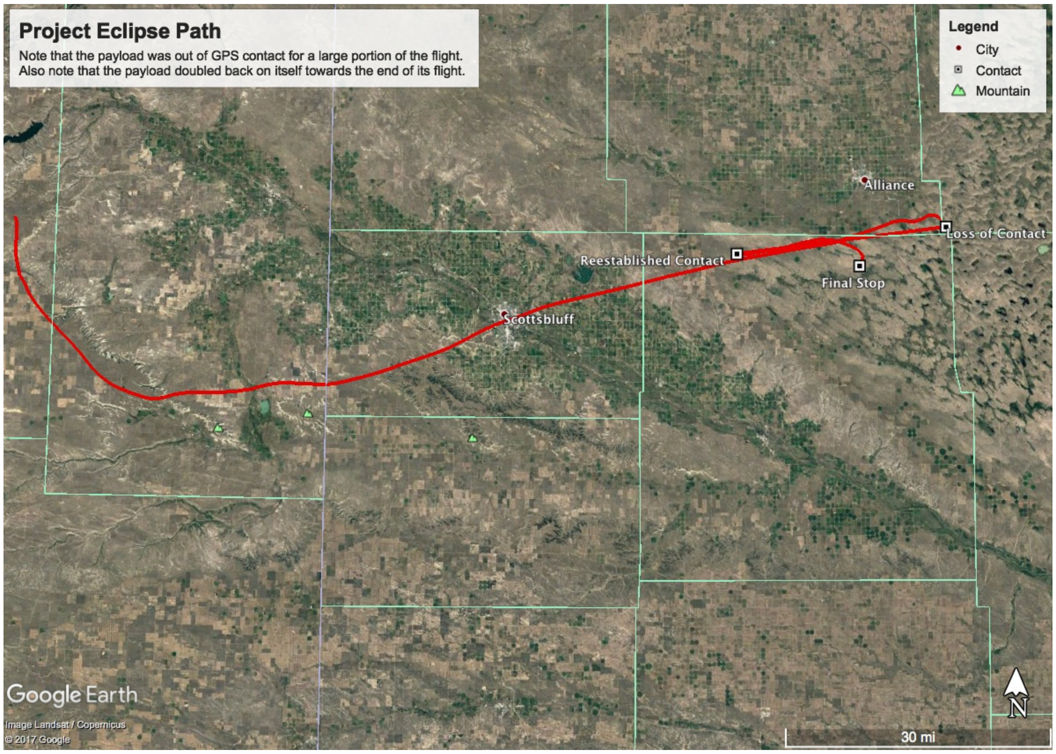


Figure 4: Map 1 of Project ECLIPSE path.

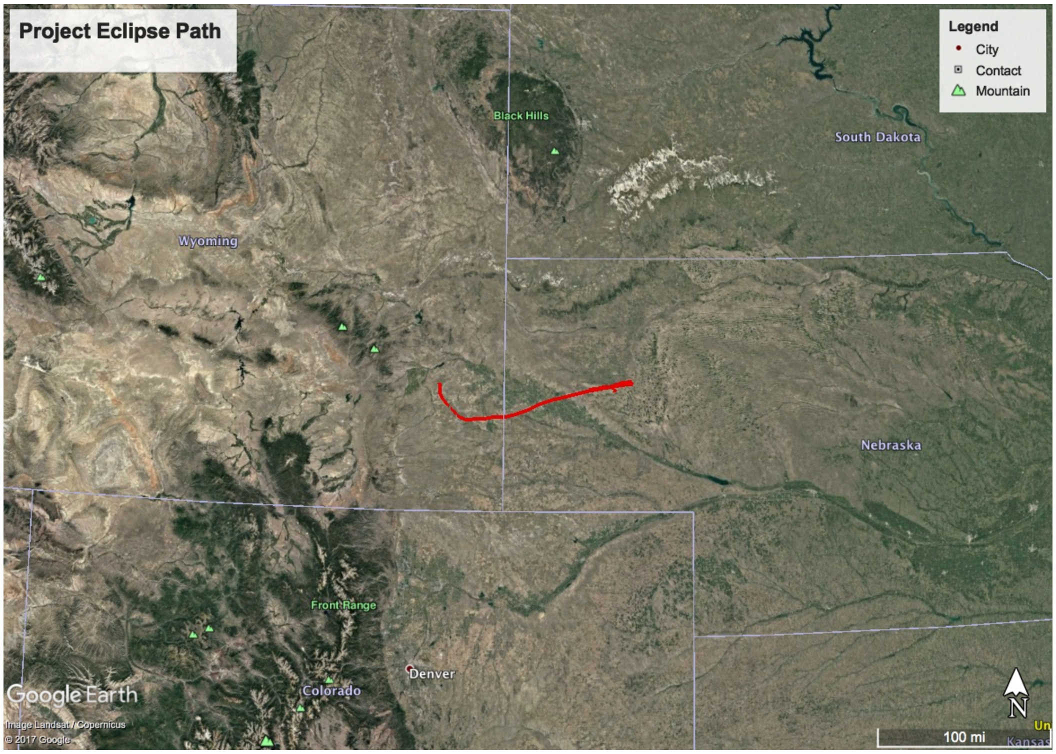


Figure 5: Map 2 of Project ECLIPSE path.

Part III

Internal Components and Software

Internal Component Summary

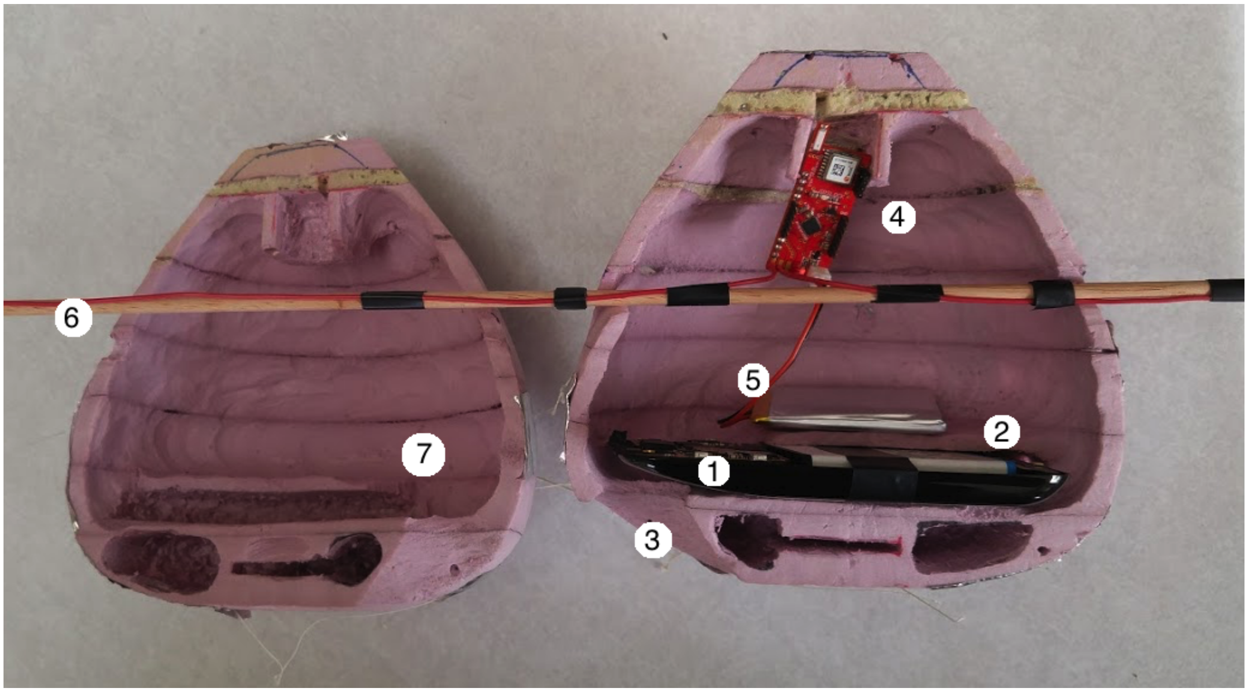


Figure 6: Cross-section of payload.

1. **Samsung Galaxy S4 Chipset** Stripped-down computer board taken from phone and reprogrammed. Contains majority of payload's sensors and stores all payload sensor data on a microSD card and in internal storage.
2. **Chipset Battery** Increased capacity lithium-ion battery. 5200mAh.
3. **Chipset Camera** 13 MP camera, pointed toward the ground.
4. **Tracksoar APRS Transmitter** Leverages existing radio relays to keep payload in constant contact after takeoff; sends sensor data to ground station in real-time. Also equipped with GPS capable of high altitude positioning, along with external temperature, pressure, and humidity sensors.
5. **Tracksoar Battery** High durability lithium-ion battery. Powered the Tracksoar for 40 hours uninterrupted during ground tests.
6. **Tracksoar Antenna** Antenna wire electrical-taped to lightweight wooden dowel.
7. **Foamular 150** Insulating outer shell. Lightweight and impact resistant.

Not pictured: Parachute, balloon, and parachute lines.

Project CODENAME has developed two important operational scripts: One runs on the S4 chipset and is a highly persistent app that utilizes the phone's on-board sensors and camera; the second is a modified version of the source code shipped with the Tracksoar APRS Tracking device. These are discussed in greater detail within subsequent sections.

Samsung Galaxy S4 Chipset

This is the primary computing component of the payload. It consists of a computer board taken from a Samsung Galaxy S4 phone, reprogrammed to suit the needs of the project. See Figure 7. The chipset contains eight integrated sensors, including an RGB light sensor, magnetometer, gravimeter, accelerometer, thermometer, barometer, hygrometer, and sensors to measure orientation vectors [2]. Since all of these sensors are built into the chipset, they add no extra weight and write data directly to the phone's memory where it can be stored for later retrieval. Project CODENAME further configured the chipset to write data to an external SD card as a fail-safe.

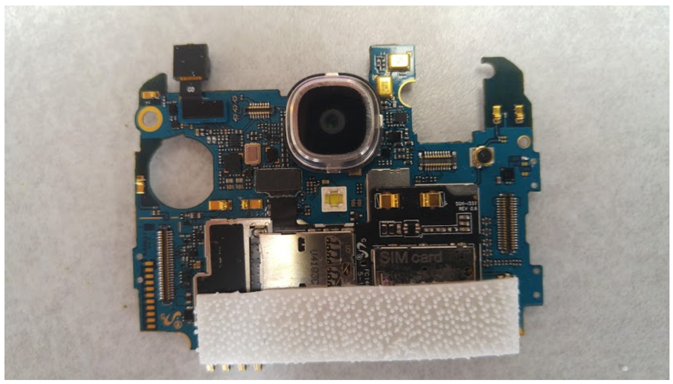


Figure 7: Chipset alone; note that the RGB light sensor, IR sensors, LED indicator, and vibration motor are missing as they were lost on impact.

Cameras In addition to the sensors enumerated above, the two chipset cameras (the front-facing and rear-facing cameras of the S4 phone, 2MP and 13MP respectively) provide two unique angles from which the payload can take photographs for the duration of the flight. Due to last-minute technical limitations, Project CODENAME flew with only the 13MP rear camera operational. Despite this setback, the payload collected nearly 350 high-quality photographs between the ground and around 100,000 feet. Several have been included in this report, but the entire collection can be found at the following web address:
`https://goo.gl/photos/KxeScd8xWUMMQ9vt6`

Figure 8: Photographs taken by rear camera on Galaxy S4 chipset (Clockwise from Top-Left: at 1300m, 3000m, 11200m, 27000m, 29700m, 4500m).

Power Supply and Battery Life The Samsung Galaxy S4 ships with a 2600mAh battery. As projections suggested this would only provide around three hours of reliable operation, Project CODENAME replaced the factory battery with an extended lithium-ion battery, doubling the capacity to 5200mAh. During ground tests, the chipset ran between six to eight hours on a single charge. During the flight, the chipset powered down with 44% battery remaining. While the cause of this is not entirely understood, it is believed to be related to overheating, as the chipset was still somewhat warm when the payload was opened. (See Temperature below).

Weight Reduction Due to the weight of the screen, Project CODENAME chose to remove the chipset entirely from the rest of the phone. Both the chipset and the battery were secured on the plastic phone back designed for use with the extended battery. The plastic phone back was perforated to increase heat dissipation and reduce weight (see figure below). All other phone components were removed.

Figure 9: Plastic phone back modified to house the chipset and battery.

Temperature The biggest hurdle encountered concerning the chipset was heat dissipation. The temperature at which the chipset was operating had a big impact on its battery life, and to examine this, it was allowed to expend one full battery charge at room temperature, one in a refrigerator, and one in a freezer. The results yielded insights into the impact of temperature on battery life as shown in the figure below.

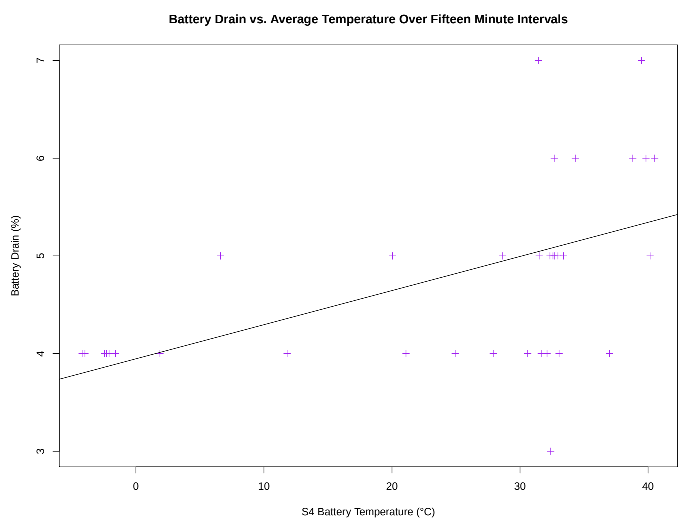


Figure 10: Graph of battery drain vs. average temperature over 15 minute intervals.

Although $R^2 = 0.273$ is fairly low (in part due to the fact that battery data is discrete), we see a clear trend: lower battery temperature results in lower battery drain. The trend-line shows that at 0 degrees C, the phone should be able to last 6 hours and 15 minutes, while at 30 degrees C, the phone would only be able to last 5 hours, which is a significant difference for our purposes. Thus, we wanted the program to attempt to maintain temperature as near zero as possible without sacrificing data collection. (Allowing the temperature to fall below zero would put us outside experimentally confirmed data.)

When running at room temperature (and often when refrigerated as well) the chipset had a tendency to overheat to the point of shutting down. In fact, when placed within the payload, the chipset overheated at a battery temperature of approximately 27°C. This issue stemmed from the excessive camera use required by the program and was exacerbated by the plastic tray and Foamular insulation, which restricted the conducting of heat away from the chipset.

To solve this, Project CODENAME made a number of minor adjustments to the programming to maintain optimal temperature conditions. Primary heating occurred on what we believe to be the RAM/CPU (which are placed one atop another on the chipset [3]), which suggested the program was conducting too much work within those two components. Heating also occurred on the microSD enclosure, which suggested the program may have been writing to said card excessively. However, no temperature sensors that can be accessed by the standard Android APIs are present on the aforementioned components, so the program attempted to prevent overheating by measuring battery temperature, which can be inaccurate in relation to the actual chipset temperature especially as the ability of the atmosphere to conduct heat decreases with air density.

At arbitrarily selected temperatures as temperature rises, the delay before the next execution of code increases. As sensor data collection and picture taking occur at different frequencies, they also have different temperatures at which delay changes. This reduces CPU load at high temperatures but also allows the phone to maintain reasonable temperatures internally when the external temperature is extremely low by working with the insulating capacity of the Foamular. This was demonstrated in-flight, as between 10km and 20km of altitude, the phone maintained approximately $-10°$C even when atmospheric conditions are usually $-60°$C.

Figure 11: Entire chipset tray as it flew in the payload.

Tracksoar APRS Transmitter

The Tracksoar APRS transmitter is the second computing component aboard the payload. While it is equipped with several sensors (specifically a GPS sensor along with external temperature, pressure, and humidity), it primarily serves as the point of contact between the payload and the ground. The transmitter transmits the payload's location (and its sensor readings) on the 2 meter amateur radio band, where it is picked up by the APRS relay system and can be received anywhere in the state of South Dakota, as per requirement 2 of the HAC. This allows for constant monitoring of the payload's position and exact conditions. The Tracksoar ships with a two AA battery power source purported to provide 12 hours of continual transmission, but Project CODENAME chose to upgrade to a high-density LiPo battery. This allowed the Tracksoar to operate for over 40 hours during ground testing.

The Tracksoar that accompanied the payload on the balloon flight was actually the third Tracksoar device Project CODENAME worked with. The first device shipped to CODENAME had an undetermined issue that eventually resulted in a critical failure of the entire device. The second device had the same issue, which was finally determined to be a problem with the electrical design of the Tracksoar board itself. Finally, a third Tracksoar was acquired that did NOT have this issue. However, programming on this third computing component revealed a problem in either the official source code or the ATMEGA328P that resulted in the Tracksoar freezing and becoming inoperable after random intervals of time. Project CODENAME fixed this problem by leveraging the existing watchdog timer on the ATMEGA328P to interrupt and reset the Tracksoar when it froze for too long. A working version of the source code is available on Project CODENAME's Github.

The program was also configured to fit Project CODENAME's specifications, and the antenna (shipped as a wire) was mounted on a light wooden dowel with electrical tape. This allowed it to extend on either side of the payload without adding significant weight. See Figure 16 in Part IV Section IV for a photograph of the Tracksoar installed in the Foamular shell.

In flight, the Tracksoar performed essentially as expected, maintaining transmissions to the APRS system every 30 seconds for all 9 hours of the flight before the battery disconnected on impact. Although the Tracksoar's transmission radius depends on the sensitivity of the receiver, it can be noted that our signal was received in places as varied as:

- Grand Forks, ND (N0RNB-5/KC0SD-3)
- Cheyenne, WY (WB7GR-2/-10)
- Yankton, SD (KC0QWN-10)
- Bismarck, ND (W0BIS-8)
- Omaha, NE (K0USA-15)
- Denver/Aurora, CO (W0ARP-3)

The Tracksoar stopped transmitting when the payload made contact with the ground as the battery connection was shaken loose, but it resumed normal function as soon as it was re-connected to its power source.

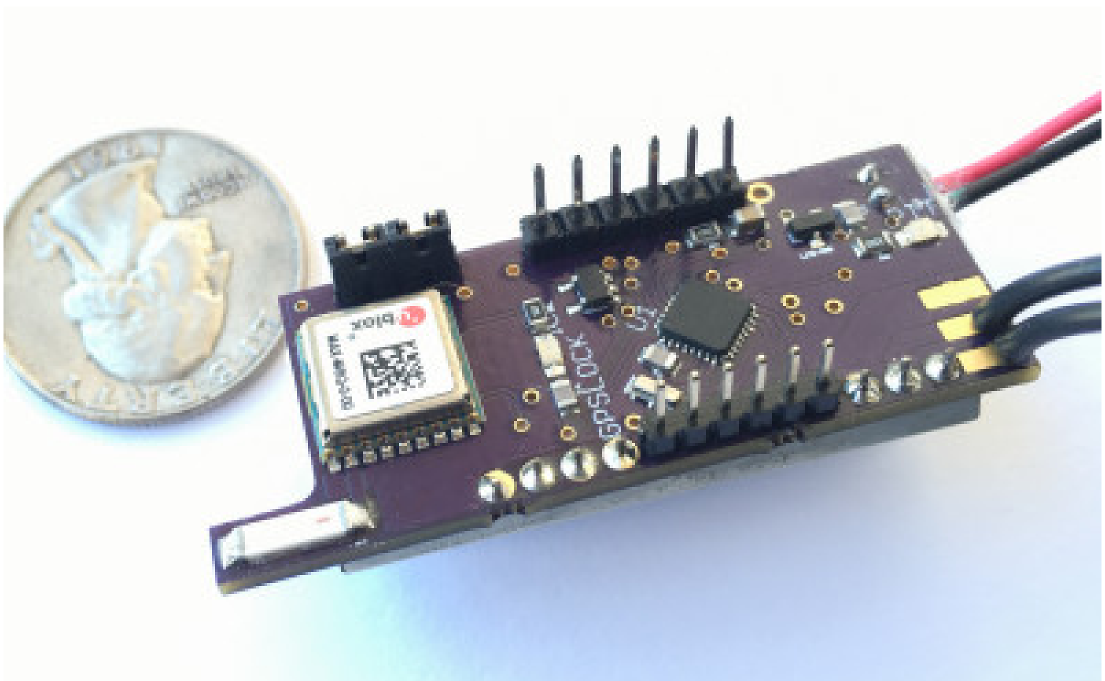


Figure 12: A Tracksoar APRS Tracking Device shown alongside quarter for scale. Antenna and battery not pictured.

Sensors

While the High Altitude Challenge requires only four sensors (internal and external temperature and pressure), the Project CODENAME payload was equipped with a total of 16 distinct sensors distributed among the two computing components described above. This section examines the purpose of each sensor or sensor group. In this discussion they have been loosely grouped into two categories as shown below.

Category 1

Sensors relating to the management and operation of the payload itself. These sensors provide an invaluable source of information on the behavior of commercially-available computing components in satellite-like conditions, specifically providing insight into the impact of high-speed motion and extreme temperature.

- **GPS (latitude and longitude) and altimeter:** These sensors provide the payload's exact position. This is the data used by the ground station to track the payload's flight path.
- **Accelerometer and orientation vector sensors:** These sensors allow the payload to determine its exact orientation at all times; the data can be used to recreate how the payload is turning or spinning in the air. Furthermore, these sensors allow us to observe and model the physical motion of the payload throughout flight. The accelerometer also meets requirement 8 of the High Altitude Challenge.
- **Internal thermometer, internal barometer and internal hygrometer:** Measures the ambient temperature, pressure, and humidity, respectively, on the inside of the payload. This provides important data on the internal operating conditions of the payload, as per requirement 5 of the High Altitude Challenge.

Category 2

Sensors relating to the capture of unique scientific data. These sensors were used to indirectly monitor the payload itself and the conditions it experienced at a given time or altitude, providing greater context for the information gathered by Category 1 sensors and providing redundancy in several cases.

- **External thermometer, external barometer, and external hygrometer:** Measures the ambient temperature, pressure, and humidity, respectively, on the outside of the payload. This data provides information on atmospheric conditions around the payload, and the thermometer and barometer meet requirement 5 of the High Altitude Challenge.
- **Gravimeter:** Measures the strength of earth's gravitational field at a given altitude.
- **Magnetometer:** Measures the strength of earth's magnetic field at a given altitude.

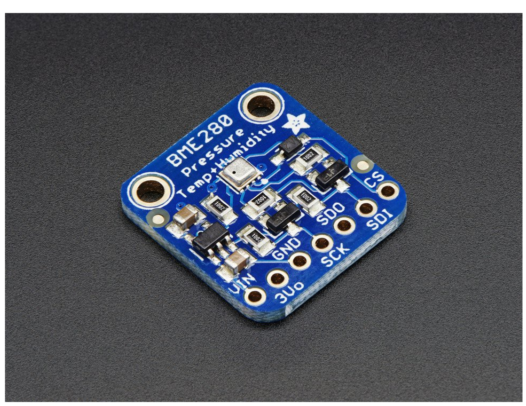


Figure 13: BME280 Sensor used by Tracksoar to measure temperature, pressure, and relative humidity.

Extensions to Project ECLIPSE

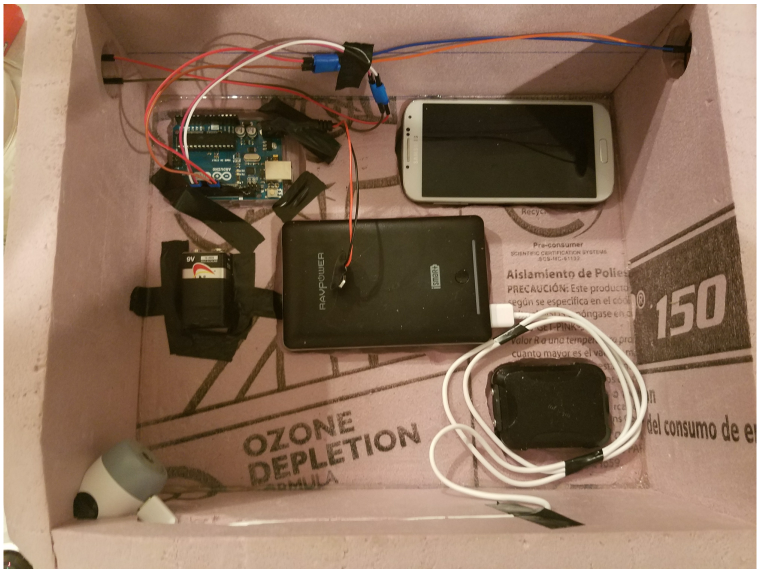


Figure 14: Project ECLIPSE cross-section.

The Tracksoar was originally intended to be included in this configuration; however, in the failed first launch of Project ECLIPSE the device was utterly destroyed and was not launched with the successful second launch.

1. **Samsung Galaxy S4 Chipset** (upper-right corner) Used as in Project CODENAME, apart from the re-attachment of the screen and attachment to the centralized power source (see below). The chipset performed admirably, staying alive for over 30 minutes even after the payload had touched back down.

2. **Centralized Power Source** (center) The lack of a weight restriction on Project ECLIPSE allowed for the inclusion of an extra power source to extend the life of the Gear 360 and chipset. Due to last-minute overheating concerns, however, the central power source was not connected to the Gear 360 camera.

3. **SpotTrace Satellite Tracking Device** (bottom-right corner) Communicated with satellites to report real-time location, as it was originally intended for tracking boats or other assets. After the loss of the Tracksoar, Project ECLIPSE relied entirely on it to report location data. This device reported information every 2 minutes and did not function above 60,000 feet. Despite these drawbacks, it eventually led the team to the exact location of the fallen payload.

4. **Arduino Uno and Piezzo Buzzers** (upper-left corner) Programmed to play the first two phrases of Sonata in C by Mozart [4] over and over throughout the duration of the flight to assist in locating the payload on the ground. Powered by a 9-volt battery. Unfortunately, they stopped functioning around 30,000 feet for reasons unknown.

5. **Gear 360 Camera** (bottom-left corner) Despite not being connected to the centralized power source, it filmed for approximately 6 hours (nearly six times longer than projected, possibly due to the cold temperatures) before failing at 100,000ft. To view a 3D virtual tour of the flight as seen by the camera, go to this web address: `https://roundme.com/tour/198608/view/`

Part IV

External

Housing

The housing material is Foamular 150. This is an insulating foam that is ideal for keeping the payload within operating temperature conditions, without adding unnecessary weight. The data returned by the CODENAME flight suggests that this is a viable material for a future satellite launch, especially when paired with a device programmed to maintain the temperature of an insulated container like the S4 chipset.
The payload shape was inspired by the famous Soyuz capsule, first employed by the USSR and NASA as early as 1960 but still in use today. This shape is ideal for stabilizing a craft as it reenters the atmosphere (requirement number 10 of the High Altitude Challenge requirements.) This proved particularly relevant for the payload as the parachute did not deploy.
A detailed, step-by-step description of the manufacturing process can be found on Project CODENAME's GitHub page.

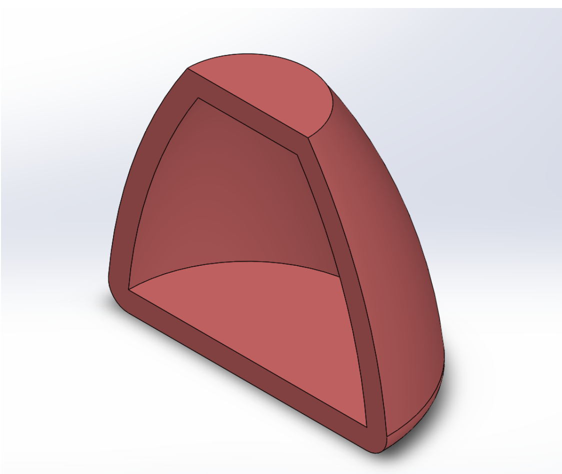


Figure 15: Rendering of Payload External Shape.

Figure 16: Fully assembled payload; note the Tracksoar antenna.

Balloon and Helium

Past teams in the High Altitude Challenge have typically used 1200 gram weather balloons; however, Project CODENAME selected a larger 1500 gram weather balloon. This increase in size was intended to allow the payload to travel higher in a shorter amount of time, at the cost of increased helium demand. See Table A.1 in the appendix for a comparison of the standard weather balloon sizes[5].

Simulations run on the GOSH Flight predictor (discussed in Part II) determined that the amount of positive lift needed for the payload to achieve the best possible combination of flight time and burst altitude was approximately 160 grams. A dummy payload was created weighing 410 grams (250+160); this was attached to the balloon as it was filled, and fill stopped when the balloon became buoyant. Sponsor A&B Welding of Rapid City donated the helium required for the flight.

Given any one type of balloon, the exact amount of helium that is needed comes from a consideration of two factors: burst altitude and flight time. As more helium is added to the balloon, flight time decreases (which is an important consideration for the battery life of the payload) but burst altitude also decreases. Conversely, less helium ensures a higher burst altitude, but a longer flight time. These relationships are demonstrated in Figure 17 for a 3000 gram balloon.

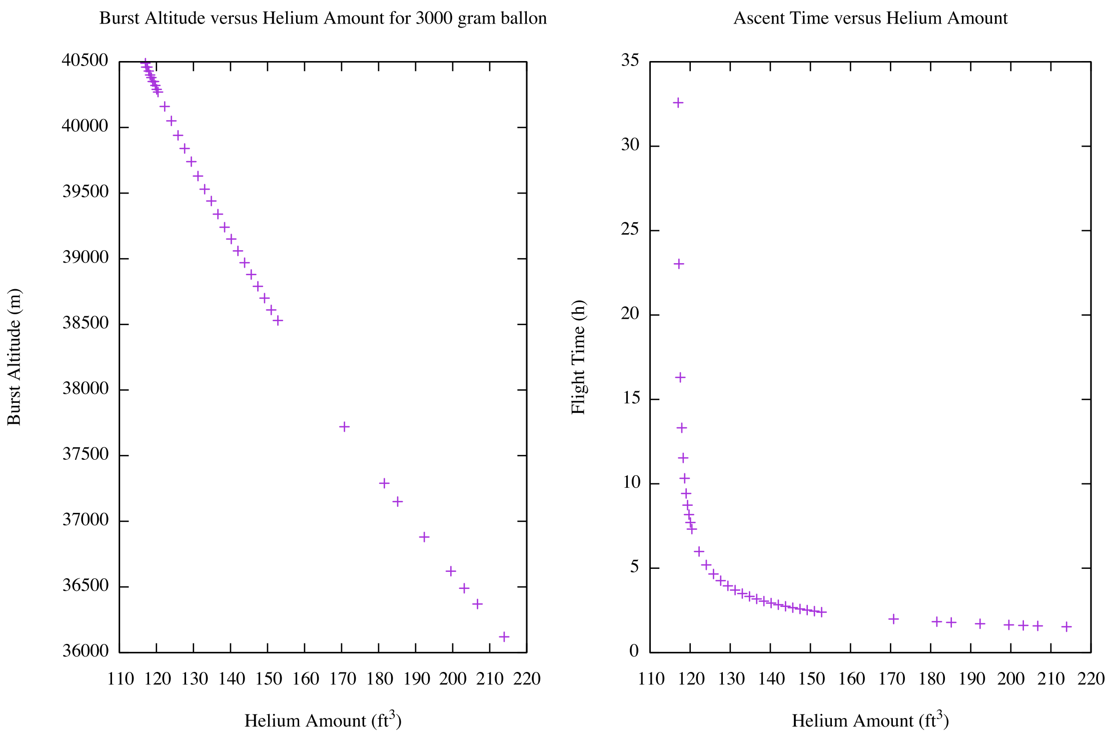


Figure 17: Graphs of ascent time and burst altitude, respectively, versus amount of helium.

Parachute

The following equation[6] is often used to calculate the necessary parachute diameter to land a payload at a given speed.

$$d = \sqrt{\frac{8mg}{\pi r C_d v^2}} \tag{1}$$

Where

d = diameter of the parachute

m = mass of payload

$r = 1.22\frac{\text{kg}}{\text{m}^3}$ (density of air)

$C_d = 1.5$ (the drag coefficient for a true, dome shaped parachute)

v = velocity at time of impact with ground

Research[7] suggested that payload's impact-resistant shell would allow it to land at speeds between $3\frac{\text{m}}{\text{s}}$ and $5\frac{\text{m}}{\text{s}}$ without sustaining major internal damage. Solving equation 1 for each of these velocities provided a range for the ideal diameter of Project CODENAME's parachute (assuming mass to be 250 grams).

$$d = \sqrt{\frac{8 \cdot 0.25\text{kg} \cdot 9.81\frac{\text{m}}{\text{s}}}{\pi \cdot 1.22\frac{\text{kg}}{\text{m}^3} \cdot 1.5 \cdot 3^2}} \tag{2}$$

$$d = 0.616\text{m} \tag{3}$$

$$d = \sqrt{\frac{8 \cdot 0.25\text{kg} \cdot 9.81\frac{\text{m}}{\text{s}}}{\pi \cdot 1.22\frac{\text{kg}}{\text{m}^3} \cdot 1.5 \cdot 5^2}} \tag{4}$$

$$d = 0.369\text{m} \tag{5}$$

Equations 3 and 5 suggested that the optimum parachute diameter for CODENAME was between 0.369m and 0.616m. Based on these figures, Project CODENAME selected the TARC-16 Parachute to accompany the payload into the atmosphere. This parachute has a diameter of 0.4064m (16"), which provides a descent rate of $4.5658\frac{\text{m}}{\text{s}}$ according to equation 1.

The parachute was tested in a drop test from the Stevens High School auditorium catwalk. A dummy payload was fastened to the parachute (approximating the weight of the actual payload) and it was filmed as it fell 34 feet to the ground. The freeware program Tracker (available at http://physlets.org/tracker/) was used to analyze the distance the parachute fell with respect to time over the last 12 feet of the fall. The resulting position-time graph is displayed in Figure 18. Since the slope is a constant $1.426\frac{\text{m}}{\text{s}}$, this was taken to be the terminal velocity of the parachute with payload attached. This was significantly different from the expected results yielded by calculations. The reason for this discrepancy is unclear, but as subsequent drop tests confirmed the experimental result, this number was adopted for calculations in balloon descent.

Unfortunately, during the flight of Project CODENAME, the parachute never deployed. This was a result of remnants of the balloon becoming entangled in the lines of the parachute on its descent. Luckily, the payload landed entirely intact with only minor external and virtually no internal damage. This is surprising as the terminal vertical velocity of the payload was approximately 10 m/s and it impacted the ground with a horizontal velocity of approximately 30 m/s, which is significant. This resilience, at least in part, can likely be attributed to the workmanship of Nathan Wiley in constructing and shaping the majority of the outer shell.

The outside of the parachute was painted in phosphorescent paint; this would have increased the visibility of the payload on the ground during a night search, providing a secondary method for locating it after descent as per requirement 3 of the High Altitude Challenge.

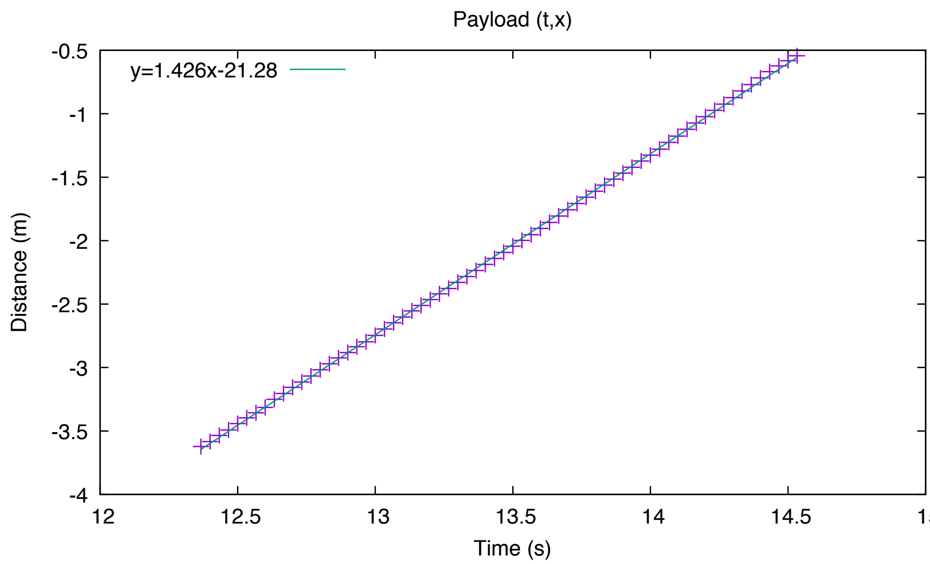


Figure 18: Position-time graph showing terminal velocity of TARC-16 parachute and dummy payload.

Balloon being released by launch team.

Extensions to Project ECLIPSE

Observations from Project CODENAME indicate that the shape of the housing is not as important in determining the success of a payload landing as is commonly thought. This is largely due to the fact that the effect of drag on the payload is negligible compared to the much larger effect of drag on the parachute. Given this consideration, and the lack of a weight restriction on Project ECLIPSE, the payload housing was a simple box with 1-inch thick walls.

The most notable outcome of Project ECLIPSE's housing design was the development of a strategy for reducing how much of the Gear 360's field of view was interrupted by the payload itself. It is an important consideration for balloon launches that intend to use a 360° camera; this type of camera is typically fragile and cannot be extended far from the payload, and yet the closer it is to the housing the less effective it becomes as the housing blocks some of the view. A solution is to carefully slope the edges of the camera hole away from the camera, making the grade less and less steep. See Figure 19 for side and front views of the modified corner, as well as a top view of all four corners. This was accomplished, once again, by the expertise of team member Nathan Wiley. While the payload remains in view, Project ECLIPSE demonstrates that such careful shaping of the housing allows the payload to occupy such a small percentage of the total viewing area that it has little impact on the quality of the footage.

This is helped by the fact that the handle of the Gear 360 occupies a blind spot; that is, the camera sees around anything placed within that region. Theoretically, future 360° cameras designed with a blind spot large enough to encompass a small payload could provide an uninterrupted field of view. However, this likely would not be possible with a single camera and instead would require multiple lenses mounted on opposite ends of a payload. Image software would then have to stitch the images together to gain a truly uninterrupted 3D image.

Figure 19: Corner designed not to impede the 360° view of the Gear camera.

All payload components were taped to the bottom of the box with electrical tape, and small holes were drilled for the piezo buzzers. The lid was sealed with reflective aluminum tape. However, Project ECLIPSE was careful not to place aluminum tape in such a way that it was likely to create glare that could subtract from the photographs of the Gear 360.

Figure 20: Examples showing that while the payload was often in view, its impact on the quality of photos retrieved was negligible.

To keep the balloon from blocking out a significant part of the camera's view, the payload was attached at the end of 50 feet of fishing line. Consequently, even though the balloon had expanded significantly by the end of the flight, it never subtracted from the viewing area in a major way.

In contrast to Project CODENAME, the descent of the ECLIPSE payload seemed to have been successfully slowed by the parachute, despite the fact that some remnants of the balloon were left in the lines. This conclusion comes from data collected by the chipset sensors and the final position of the payload as the Gear 360 was not operating during descent. Specifically, the final downward velocity of the payload before landing was approximately 8 meters per second vertically, and the parachute lines were fully extended, suggesting the parachute was fully engaged before landing. In fact, some sensor data and photo evidence suggests the payload may have been drug around along the ground by the parachute and tipped over *after* landing, though this is difficult to confirm.

Part V

Data Collected

This is a discussion of the data collected by the chipset and the Tracksoar from launch to landing.

Data Verification

When flown, the payload contained three different temperature sensors (S4 ambient, S4 battery, and Tracksoar), two different pressure sensors, and two different relative humidity sensors. To verify that the sensors were not malfunctioning, these data can be compared. The Tracksoar data is considered more reliable as the Tracksoar was made for the purpose of high-altitude ballooning, while the S4 was (obviously) not.

Temperature

Plotting Tracksoar temperature vs. S4 battery temperature after converting S4 values to degrees Celsius demonstrates a general linear correlation. However, the trendline has equation:

$$y = 1.06x + 5.12$$

This model is highly accurate, with $R^2 = 0.9527$. This suggests some systemic error on behalf of one of the sensors, as the trendline has slope very close to 1. This could be explained by the rising of heat within the payload and the vicinity of the S4 to the open air, but these effects most likely are not large enough to generate five degrees worth of difference.

A model assuming the two should return the same value at every data point (that is, the sensors perfectly match each other) has $R^2 = 0.6190$, however, incorporating a systemic error of 5.12 results in the R^2 value jumping to 0.9492. These high R^2 values suggest that the data returned by the two sensors are most likely accurate, although one or both of the sensors may have a systemic error in measurement.

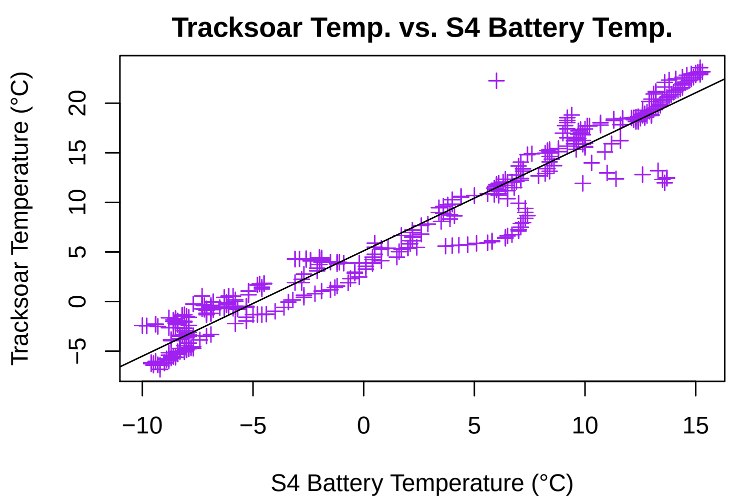


Figure 21: Temperature-temperature graph demonstrating the general correlation between the measurements of temperature by the Tracksoar and the S4 battery temperature.

On the other hand, the S4's temperature sensor reports a set of data which, although correlated ($R^2 = 0.8577$) with the Tracksoar's data, appears to be inaccurate. The return value should be in degrees Celsius, but the recorded values appear not to be in any common temperature unit. This suggests that the SHTC1 temperature and humidity sensor may no longer be calibrated. This hypothesis will be discussed further in the Relative Humidity subsection. In order to test this hypothesis, future launches with the S4 will continue to collect this data and analysis will be done to determine if the current trend-line model continues to hold or if the data is simply noise.

Unfortunately, the Tracksoar's more reliable temperature sensor did not launch with Project ECLIPSE, preventing cross-validation of the model.

Pressure

Plotting Tracksoar pressure vs. S4 pressure after converting the Tracksoar values to hPa results in an extremely linear graph. In fact, fitting a trendline to the data (as shown below) results in a line with equation:

$$y = 0.988x - 0.789$$

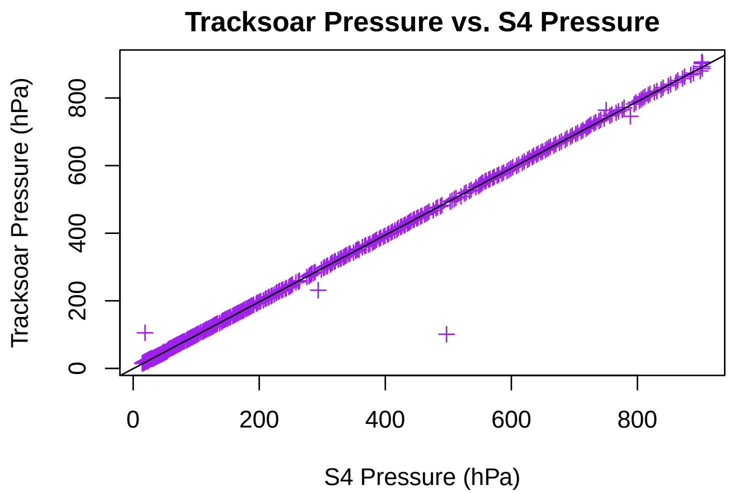


Figure 22: Pressure-pressure graph demonstrating the accuracy of the two pressure sensors.

This equation models the data with $R^2 = 0.9952$, which is extremely high. In fact, a model assuming that the S4 and Tracksoar sensors return the exact same value at all data points (that is, they perfectly match each other) results in $R^2 = 0.9948$. This demonstrates that the two are extremely well-matched and that the data returned by the two sensors are probably both extremely accurate. The 0.789 hPa difference may partially be accounted for by the small difference in height between the Tracksoar and the S4, which could have had an impact on the scale of about 0.1 hPa. Other contributors were likely differences in sensor calibration and systemic error as well as various outliers such as the point at approximately (500, 100).

Relative Humidity

There appear to be many outliers in both sets of data for relative humidity. For example, there are many S4 measurements of 100% RH. This is a pattern consistent with a highly decalibrated sensor, as the high frequency of readings at exactly 100% suggest that the sensor frequently returned results greater than 100%, which the program returns as 100% as it is not designed to interpret numbers outside the bounds of 0-100.

After throwing out these measurements as well as various outliers from the Tracksoar data, we arrive at a value of $R^2 = 0.328$, which is still very low. This is not surprising as the RH sensor often depends on its accompanying temperature sensor to return accurate results, and the S4 temperature sensor was demonstrated to be highly unreliable (see above.) Additionally, relative humidity sensors are generally very sensitive to temperature changes and calibration drift, which may have contributed to the variance measured in this data.

Physical Motion

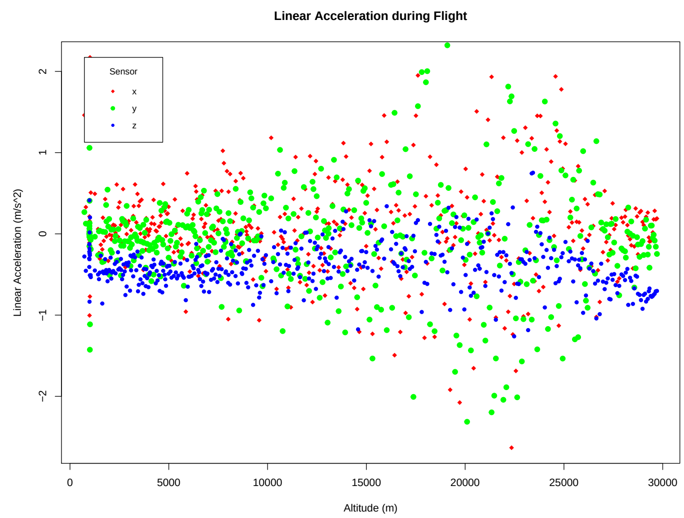


Figure 23: Acceleration-altitude graph showing three-axis acceleration during flight.

The data in the z-axis shows a general and consistent upwards acceleration, as should be provided by the balloon. This becomes less consistent between 15,000 and 25,000 meters, at the same time that the acceleration in the x and y-axis grow substantially. This most likely indicates an arrest in the ascent of the balloon along with significant swinging of the payload. After this the x and y values cluster around 0 again and the z values become consistent with a stronger ascent, though they never become as consistent as before. (We think, anyway. One writer of this paper is colorblind, which makes it really hard to tell what is happening in that graph.) Please note that the data collected by the S4 uses a linear accelerometer, which disregards acceleration due to gravity. Please also note that the accelerometer defines the z-axis as out of the screen, which is generally down [8]. Thus, a negative acceleration in z means an upward acceleration of the balloon.

The data discussed above confirms a well-known challenge of high-altitude ballooning: any instabilities in the air can result in a swinging payload, especially as the balloon slows down. It is worth noting, however, that our flight demonstrates that swinging and spinning are less of a challenge than it is often anticipated to be. No aberration was detected in any piece of equipment even during the most extreme swings. This includes the camera, which was one of the greatest concerns: our conclusion is that the camera is already viewing such a wide angle that the motion of the payload has little impact on the quality of the photos being taken. The conclusion is reinforced in further discussions of rotational motion experienced by the payload in other parts of this section.

The period of chaos between 15000 and 25000 is also demonstrated by the rotation vector sensor. This sensor measures rotation **around** an axis, with z defined as up. Thus, rotation around z is spinning, while rotation around x and y is swinging (where the payload is no longer pointed straight up). The value from the sensor given is $sin(\frac{\theta}{2})$, where θ is the rotation around the axis [9].

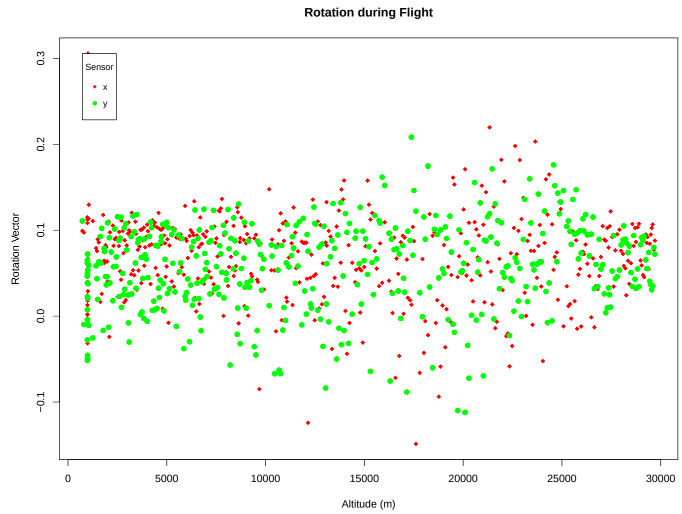


Figure 24: Rotation-altitude graph showing swinging during flight.

It is evident from the data shown above that swinging increases between 15000 and 25000 feet, reaching a maximum of 24.04° in the y-direction and 35.59° in the z-direction. It can further be noted that the payload appears to be tilted slightly throughout the entirety of the flight, with an average tilt of 7.750° and 6.47° in the x and y-axes, respectively, suggesting that the parachute lines and/or internal payload design were not perfectly flat with respect to the horizontal. It is possible that the wind generally blew the payload in a way that tilted it in one direction (as x and y are defined around East and North, respectively). However, these data, which show a positive trend for both values, are only partially consistent with weather data for that day (with winds blowing Southeastward), although they are consistent with a jet stream going Northeastward.

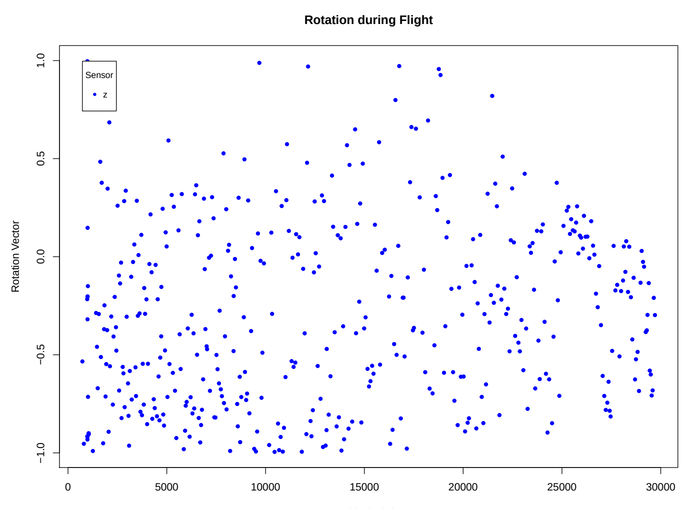


Figure 25: Rotation-altitude graph showing spinning during flight.

The use of a simple rotation vector vs. altitude graph for the z-axis does not provide much insight into the payload's flight, but a graph of the angular velocity (estimated via the difference quotient) over time does yield some interesting conclusions.

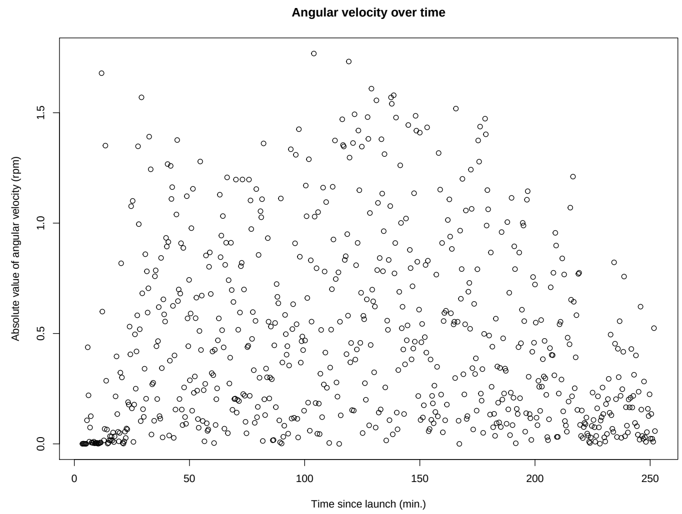


Figure 26: Angular velocity-time graph showing spinning during flight.

The graph uses the absolute value of angular velocity in order to determine the magnitude of the spinning without consideration for direction. It appears that the intensity of spinning increases consistently for the first portion of the flight, peaking at around 130-140 minutes after launch (when the payload is at approximately 15000 feet in the air) before decreasing. Note that this analysis neglects the fact that some of these data points may suffer from wrap-around, where the payload makes over a full rotation before a second data point is measured (at the current data polling rate, a spinning rate faster than approximately 3 RPM cannot be measured), or where the payload rotates from a 179 degrees to -179 degrees, although those data points should have been rejected as outliers. This is an important consideration for future launches: if rotation data is required, an increased polling rate or a more robust sensor will be needed to provide more accurate measurements. Most commercially available equipment with this type of sensor will not come prepared for this level of measurement, though many can be successfully converted.

Magnetic Field

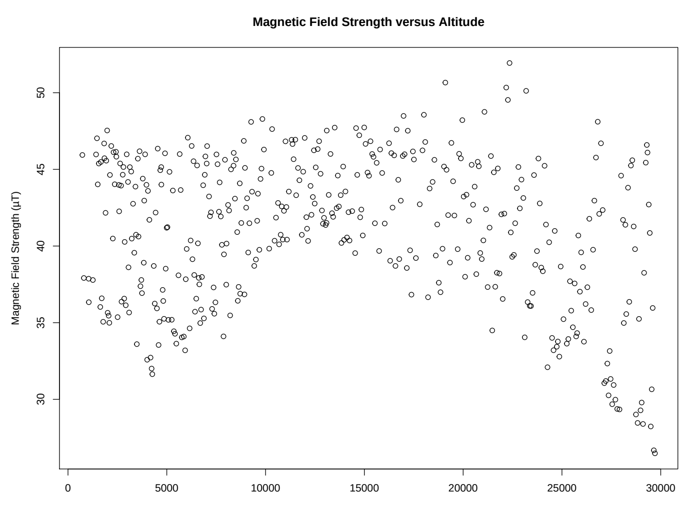


Figure 27: Magnetic field strength-altitude graph showing changes in the field during flight.

The graph takes the vector sum of the magnetic fields measured in the x, y, and z axes to get the magnitude of the magnetic field at each point. The physical motion of the S4, as discussed in the above section, would affect the measurements by changing the axes relative to absolute coordinates, which would make calculations difficult. It can be noted that the data become less diffuse between 10000 and 20000 meters, which makes it difficult to model the data, but there is a general trend for the field strength to decrease as altitude increases.

The International Geomagnetic Reference Field (IGRF) model, a standard model for the magnetic field, does not fit any of our data, especially as altitude increases [10]. However, the IGRF model has been shown to be inaccurate in modeling the magnetic field at high-altitudes on other High Altitude Balloon flights [11]. It can be further noted that the values reported by the code is within the range generally accepted for Earth's magnetic field (25-65μT) and displays the same trend suggested by the paper, which is that magnetic field intensity decreases with altitude.

While the data matches the general trend mentioned above, it must be noted that the values returned for the strength of the magnetic field even at ground level are significantly different than expected, requiring an exploration of several possible explanations. For example, it is possible that the Earth's magnetic field has changed faster than the IGRF assumes or some specific event affected the magnetic field that day. It can be noted that there was a K=4 geomagnetic variance recorded on that day at the Boulder, CO NOAA/SWPC station [12], but this minute change is unlikely to have caused the effects seen. It is also possible that there was magnetic interference from other electronic equipment, although if this were the case we would expect more variance due to rotation and swinging, and it is possible that the phone's magnetometer is simply imprecise/decalibrated. Further testing and future launches with the S4 are required to fully investigate this issue.

Atmospheric Data

Temperature

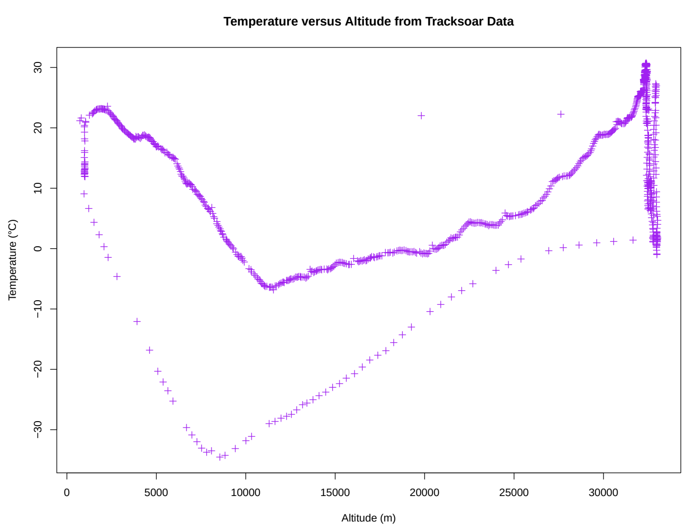


Figure 28: Temperature-altitude data from the Tracksoar.

The temperature and altitude data demonstrate two different sets of data: the ascent and the descent. During the ascent the temperature is much higher than on the way down, although in both cases the minimum temperature occurs at approximately 10000 meters. This is consistent with standard models of atmospheric conditions. We then mark the maximum temperature at the top of the flight at approximately 30000 m. However, the measurement of a temperature as high as 30 $^{\circ}C$ is significant, as the atmospheric temperature at 30000 meters should be between -20 and -40 $^{\circ}C$. This difference between the measured and atmospheric temperatures could easily have been caused by the insulating capabilities of Foamular.

The difference between ascent and descent temperature could then have been caused by the fact that air circulation through the camera hole located at the bottom of the payload increased on the way down due to increased velocity. Furthermore, the possibility of the Samsung S4 contributing to the continued warmth of the payload on the way up is not one to be neglected. This becomes all the more evident when we examine Temperature-Time data.

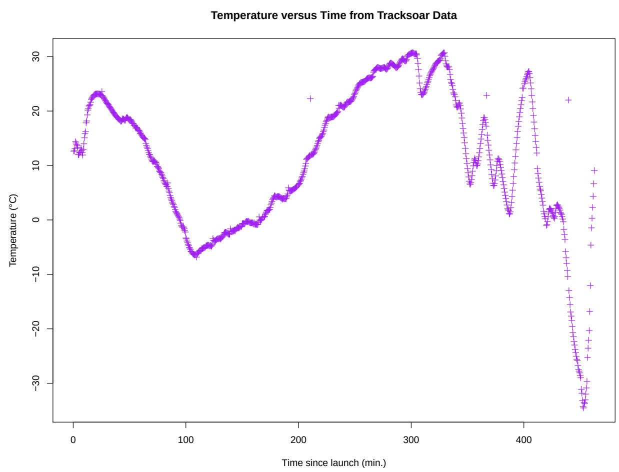


Figure 29: Temperature-time data from the Tracksoar.

There is a notable slowing in heating after approximately 250 minutes, which is the same point at which the S4 stopped recording data. Given this, it is possible that the S4 was able to maintain the warmth of the payload on the ascent until it died. However, examining the Temperature-Time data also suggests a problem with the hypothesis that the Foamular is responsible for the major difference between measured and atmospheric temperatures and thus leaves an unsolved conundrum. The temperature of the payload actually decreases from 30 degrees to zero degrees before rising rapidly back up to about 27 degrees. This should not be possible without some form of active heating even given insulation. One possibility is that there are different air masses at this altitude with dramatically different temperatures. However, there is no verification for that and there are many other possibilities that need to be explored in relation to this anomaly.

Pressure

There is nothing particularly notable about the pressure data collected by the Tracksoar, simply that it seems to be accurate. It fits the standard barometric curve (using the recorded barometric pressure of 1017.6 hPa for May 21st) with an $R^2 = 0.987$, which is extremely high.

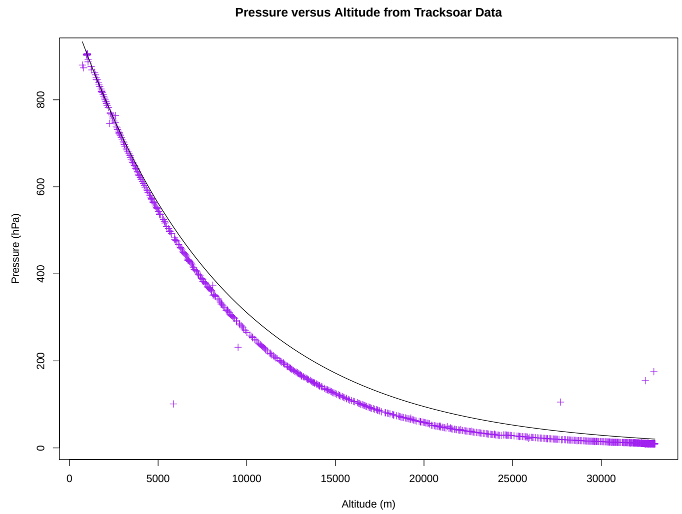


Figure 30: Pressure-altitude data from the Tracksoar.

Although it appears that this pressure data deviates from the curve, it should be noted that both the S4 and the Tracksoar recorded this deviation, suggesting that the data is accurate and this deviation is mostly insignificant, resulting in a high R^2 value. Generally, these measurements are consistent with expectations and most likely accurate, and can probably be trusted in the future.

Relative Humidity

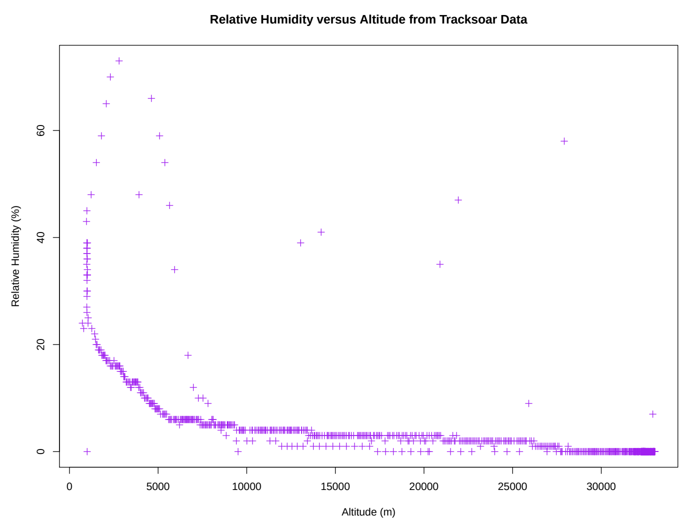


Figure 31: Relative humidity-altitude data from the Tracksoar.

It should first be noted that there are two different sets of data being recorded here: the ascent and the descent. During the ascent, which is the set of data that is more densely packed together, the relative humidity decreases constantly until it approaches/reaches zero at approximately 28000 feet. Further research, however, indicates that many relative humidity sensors do not function well at altitude and may not account for the decrease in air pressure. This problem may have affected the Tracksoar, although we have no verification of that possibility.

The data during the descent, on the other hand, is much more interesting. Although it is sparser (as the descent rate is faster than the ascent rate), the data demonstrates a significant increase and then decrease in relative humidity between approximately 7000 and 2000 meters. This suggests that the balloon passed through middle altitude clouds on its way down to the ground. (These clouds may have then proceeded to rain upon the authors and the recovery team on the way home). This result increases our confidence in the technology for launching through clouds if necessary, although actual experiments are necessary to test if the components are truly cloud-proof. Furthermore, the relative humidity data then appears to converge on the same value as it started at, suggesting that ground conditions did not change significantly between launch and landing.

Extensions to Project ECLIPSE

Unfortunately, the Tracksoar was lost before launch, meaning that questions about decalibrated sensors and a deviation from the standard pressure-altitude model cannot be addressed. Furthermore, this means that all altitudes in this section are derived from a calculation from the standard barometric curve, which may differ from the actual altitudes - this cannot be determined without the GPS data from the Tracksoar.

Physical Motion

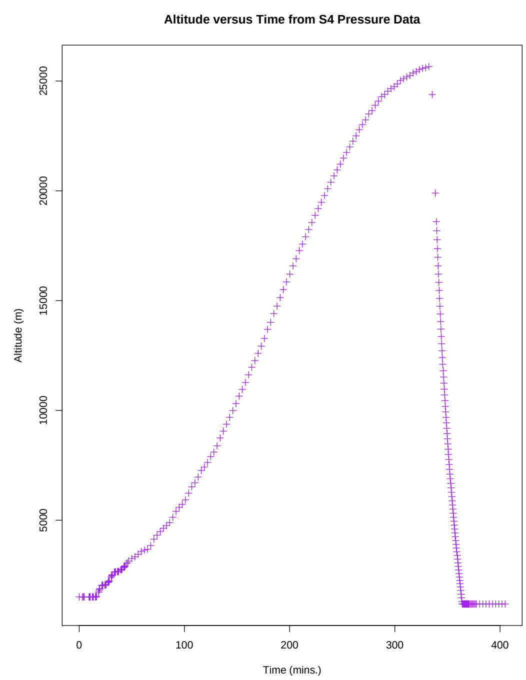


Figure 32: Altitude-time graph for ECLIPSE.

Using the pressure measured by the S4, it appears that during the first 70 to 90 minutes of flight the altitude of the balloon rose very slowly before it started to accelerate, slowing down as it reached around 25000 meters, before rapidly descending after balloon burst. Interestingly enough, the S4 continues to function on the ground for about 40 minutes, demonstrating an extremely successful deployment of the overheating prevention code. During this time, it recorded a minor variation in pressure, representing an altitude decrease of 2 meters or so.

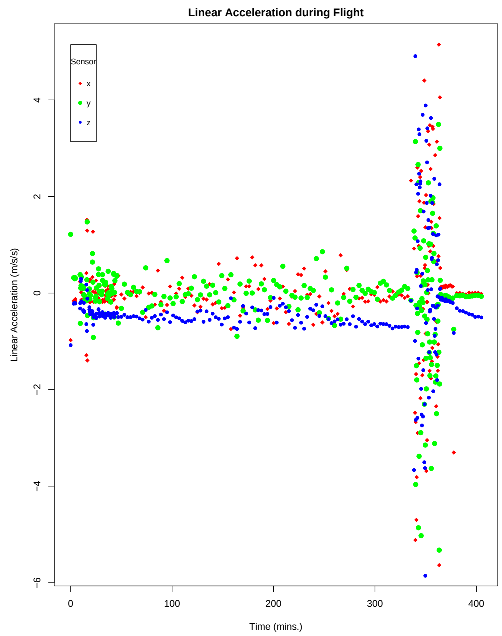


Figure 33: Linear acceleration-time graph for ECLIPSE.

In terms of acceleration, the data in the z-axis shows a similar general and consistent upwards acceleration, while acceleration in the x and y axes cluster around zero. This is, of course, until the balloon bursts, where the acceleration graph becomes basically random, caused by stochastic wind currents, swinging, and spinning. After landing, acceleration in the z-axis (which now corresponds to acceleration in whatever direction the phone screen is oriented) is recorded, variable, and non-zero, suggesting possible movement on the ground.

This more peaceful flight is also demonstrated by rotation vector data - swinging (measured by rotation around x and y) is virtually non-existent until the balloon bursts. Another notable effect is the flipping over of the payload on the ground, which is shown by the more extreme x and y values at the end of the flight. The change in x value seems to be more gradual, however, and suggests continual movement of the payload while it is on the ground.

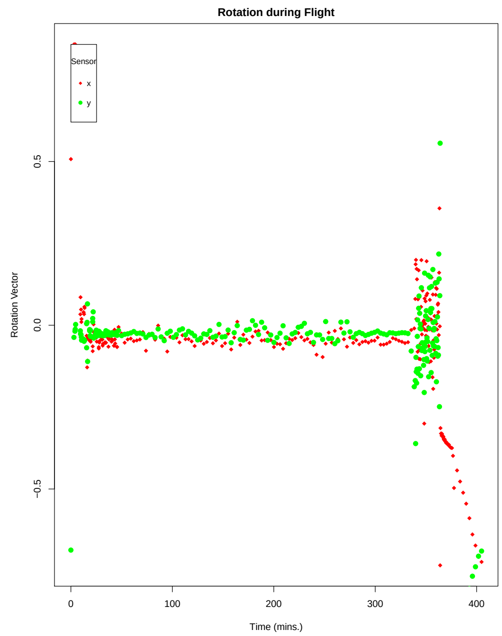


Figure 34: Rotation-time graph showing lack of swinging during ECLIPSE.

Notably, this payload seemed to hold an even smaller average tilt than the last one, possibly due to better machining or parachute line design (with an average of 3.44 and 0.84 degrees around each axis during ascent).

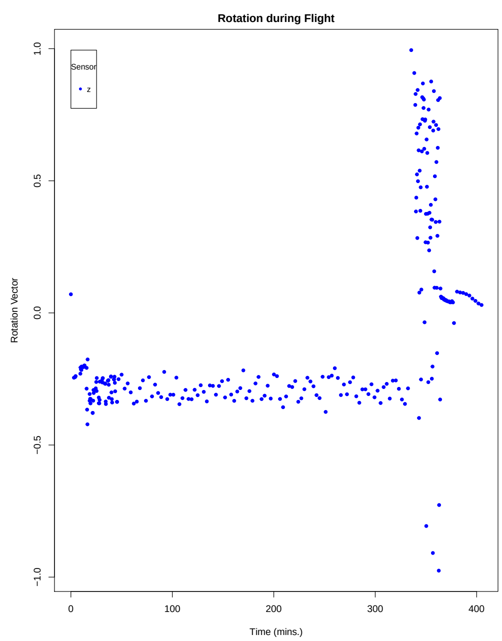


Figure 35: Rotation-time graph showing lack of spinning during ECLIPSE.

The use of a simple rotation vector vs. altitude graph for the z-axis in this case does provide an interesting opportunity for analysis in this case - the rotation direction is generally consistent during ascent, which could be a result of a better line design that reduces the amount of spinning (possibly due to the moment of inertia). Furthermore, most spinning simply goes back and forth. Note that sensor polling was exceptionally slow for this flight due to high temperatures, which could have caused missing measurements, but random sampling is unlikely to get such a consistent measurement range over all five plus hours of flight. Furthermore, the spinning and swinging is highly consistent with what is observed in the video footage captured by the Gear 360.

Magnetic Field

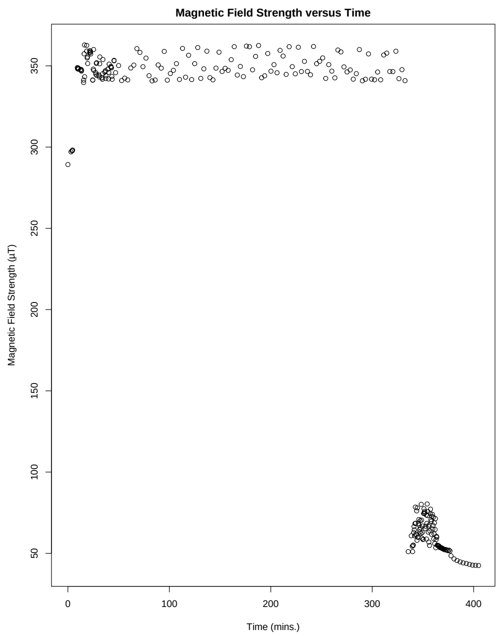


Figure 36: Magnetic field strength-time graph for ECLIPSE.

Taking the vector sum of the strength of the magnetic field gives us a value that is far too high to be consistent with the actual magnetic field, and the trailing end of the graph seems to present a sudden jump to data that would be more realistic. This discovery seems to invalidate any measurements from the magnetic field sensor, which might only work under certain conditions or just be completely broken - this is unfortunate for any data analysis done for CODENAME, but does seem to back up the hypothesis that the magnetic field sensor is indeed imprecise/decalibrated.

Temperature

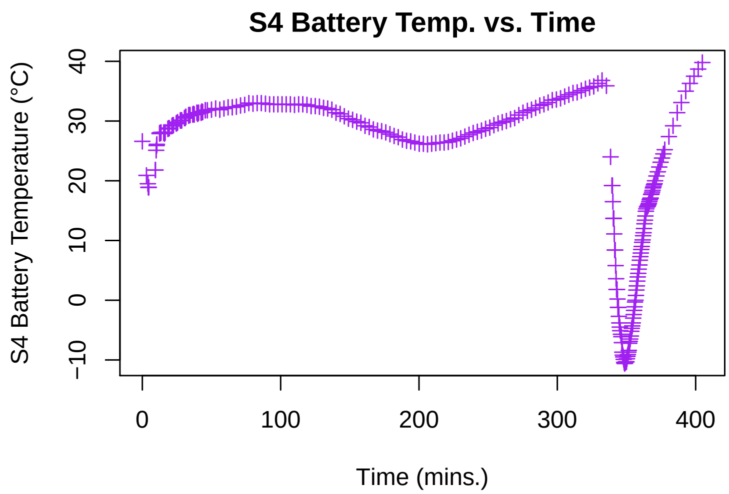


Figure 37: Battery temperature-time graph for the S4 during ECLIPSE.

This payload lacked any functioning ambient temperature sensors, but we do note from the data on the battery sensor that the S4 chipset itself (and presumably the entire payload) stayed warm throughout the whole flight, with very little fluctuation, although the local minimum in temperature during the ascent occurs at about 17000 meters, which is much later than the 10000 meters of CODENAME. Temperature proceeds to rise until balloon burst due to a lack of air to conduct heat away from the phone, reaching a maximum of 36.8 degrees Celsius (or 98.2 degrees Fahrenheit) before it rapidly drops on the way down, reaching a minimum of -10.6 degrees Celsius at about 10000 meters (as expected). After landing, the temperature of the S4 rapidly increases, and the last measurement before the device presumably overheats gives the temperature as 39.8 degrees Celsius or 103.6 degrees Fahrenheit.

The S4 was plugged in the whole time, which introduces an interesting factor to this analysis - it maintained a battery percentage of 100% throughout. One might think that the additional heat of charging might actually make overheating worse, but that effect was not seen in this flight.

Part VI

Conclusion

Successes of Project CODENAME

Project CODENAME was extremely successful in meeting and exceeding High Altitude Challenge requirements and is an advancement in the design of high altitude balloon projects in general. Not only was the Project CODENAME payload reusable, Project CODENAME succeeded in developing an easily extensible, relatively inexpensive, and completely open-source framework (available at this link: `https://github.com/Project-CODENAME/project-codename`) for launching high altitude balloons with only two components: an Android phone and a Tracksoar. This would allow for any other team to launch a payload without the necessity for writing any of their own code, and provides a large codebase for future projects to pick and choose from. Furthermore, with the support of the open-source community and other High Altitude Challenge projects, Project CODENAME's codebase could become even more diverse and robust in the future. Because the components used are compact, light-weight, and meet all needs of most balloon launches in a contained, two-device system, other teams can easily add other components or sensors of their own design without focusing on basics such as tracking. This extensibility makes Project CODENAME an extremely promising start for all sorts of future launches. In its extremely speedy recovery, CODENAME also demonstrates a more efficient tracking and recovery system that could be used in the future. Its reusability came from a strategy of limited components and no component connections, decreasing the possibility of damage of the payload on impact with ground (even in cases when the parachute does not sufficiently slow descent velocity). With all of these improvements, CODENAME marks a significant success and pushes the baseline for future High Altitude Projects even higher.

Furthermore, Project CODENAME marks significant progress across the board in advancing the efforts to eventually build a student-designed satellite. By meeting the weight limit this year, CODENAME becomes the first successful payload that meets the weight requirements for a CubeSat.

By monitoring internal temperature and battery power frequently, CODENAME allows for analysis of the effects of temperature on battery drain and extrapolation of the importance and optimal use of temperature regulation in future spaceflight. The possibility of sensor decalibration and inaccuracies must be considered on the ground, before launch, as it becomes difficult to re-scale sensor data when that sensor data is coming from hundreds, if not thousands, of kilometers away. The possibility of CPU/RAM overheating without air circulation, or air at all, really, also becomes important, while the possibility of batteries dying due to ultra-low temperatures is also extremely important. CODENAME makes advancements in solving both of these issues through programming. The resilience to spinning and high-velocity impact demonstrated by CODENAME's two-device, no-connection system sets an important precedent for surviving such stresses in a satellite launch. The integrated nature of the sensors allowed for a very high number of sensors considering the weight requirement, which is another important precedent.

Essentially, CODENAME provides important insights into understanding the potential influences that may derail a satellite launch and makes important advancements into possible solutions. A final satellite payload is likely to resemble CODENAME's payload: an integrated system without wired connections, programmed to regulate internal temperature and other conditions, and capable of far more data processing than any commercially available programmable computers (such as the Raspberry Pi).

- GitHub: `https://github.com/Project-CODENAME/project-codename`
- High Altitude Photos: `https://goo.gl/photos/KxeScd8xWUMMQ9vt6`
- Raw Data: `https://drive.google.com/open?id=0B7svtMFCcvtIallhUERHWjV4YWc`

Successes of Project ECLIPSE

Project ECLIPSE confirmed nearly all of the conclusions about potential space launches described in the previous section and demonstrated conclusively the reusability of Project CODENAME. It reinforces the potential of Project CODENAME as an ideal framework for building more complex high-altitude projects without worrying about basic but unavoidable requirements such as tracking.

The project also provides an interesting conclusion about payload shape: most likely, the exact dimensions and aerodynamics of the housing is irrelevant to the overall performance of the payload, providing that a parachute is present.

Finally, Project ECLIPSE demonstrates an inexpensive but highly effective strategy for putting a state-of-the-art 360 degree camera high into the atmosphere and returning quality photographs and videos. The original goal of photographing totality was not reached, but a significant volume of the eclipse was filmed. It is especially interesting to note that much of the eclipse footage shows a clear demarcation between ground that is experiencing a total eclipse and ground that is not. Project ECLIPSE also captured an incredible array of sub-space images rivaling that of professional enterprises.

- Selected 2D Stills from Gear 360: `https://goo.gl/photos/U9FjQvWqU1aBHh4P6`
- Photos Taken by Chipset: `https://goo.gl/photos/rK4xenATQis2LBVe7`
- 3D Tour of Launch and Flight: `https://roundme.com/tour/198608/view/`
- Full 3D Footage: `https://www.youtube.com/playlist?list=PL0IvJreDI-AYvp3Ia9Z03TiRI2HtMfreG`

Bibliography

[1] HabHub Predictive Engine
http://predict.habhub.org/

[2] Samsung Galaxy S4 Sensors
https://news.samsung.com/global/what-you-may-not-know-about-galaxy-s4-innovative-techonology

[3] Samsung Galaxy S4 Chipset Teardown
https://www.ifixit.com/Teardown/Samsung+Galaxy+S4+Teardown/13947

[4] Sonata in C
http://imslp.org/wiki/Piano_Sonata_No.16_in_C_major,_K.545_(Mozart,_Wolfgang_Amadeus)

[5] Balloon Performance Calculator
http://tools.highaltitudescience.com/

[6] Parachute Descent Calculations
http://www.rocketmime.com/rockets/descent.html

[7] Shell Impact Resistance
http://www.rocketmime.com/rockets/descent.html

[8] Android Sensor Coordinate Systems
https://developer.android.com/guide/topics/sensors/sensors_overview.html#sensors-coords

[9] Rotation Vector Coordinate System
https://source.android.com/devices/sensors/sensor-types#rotation_vector

[10] International Geomagnetic Reference Field, provided by the National Centers for Environmental Information
https://www.ngdc.noaa.gov/geomag-web/#igrfwmm

[11] "Stratospheric atmospheric surveys using weather balloons", Fong, Roberts, and Kennon, 2016. Published for the Arkansas Space Grant Consortium Symposium.
https://www.researchgate.net/publication/301894528_Stratospheric_atmospheric_surveys_using_weather_balloons

[12] Space Weather Historical Alerts, NOAA
ftp://ftp.swpc.noaa.gov/pub/alerts/

Appendices

Appendix A

Table Data

Positive Lift (g)	**Balloon Size (g)**	**He (ft^3)**	**Burst Height (m)**	**Ascent Rate $\frac{m}{s}$**	**Time (h)**
500	600	48.53	31330	4.63	1.88
500	1200	70.10	35190	4.09	2.39
500	1500	80.89	36650	3.90	2.61
500	3000	134.81	39440	3.29	3.33
1000	600	66.51	29230	5.89	1.38
1000	1200	88.08	33620	5.37	1.74
1000	1500	98.86	35240	5.16	1.90
1000	3000	152.79	38530	4.47	2.40
2000	600	102.46	26390	7.22	1.02
2000	1200	124.03	31310	6.77	1.28
2000	1500	134.81	33100	6.59	1.40
2000	3000	188.74	37010	5.89	1.75

Table A.1: Comparison of balloon size for a given amount of positive lift.

Item Number	Component	Cost (USD)	Weight (grams)
ASIN: B00O2ALRNS	Samsung Galaxy S4 (SGH-I337, 16 GB)	100.86	25.00
--	Camera Connection Cord(x2)	--	2.00
ASIN: B00S4FCLJ6	Chipset Battery	12.99	50.00
SKU: 0001	Tracksoar	195.00	40.00
--	Tracksoar-Arduino cables	--	4.00
SKU: 0007	Tracksoar Programming shield	35.00	0.00
a000053	Arduino Interface	24.95	13.00
UPC: 65030863186	Phone-Arduino cord	6.99	8.00
UPC:6955170849291	SainSmart MQ131 Ozone Sensor	23.98	8.50
SKU: 1631286	Foamular Sheets (Housing)	51.29	13.00
none, Model: TARC-16	Parachute	27.00	35.00
--	Fishing Swivel & Kite String	--	0.30
WS2812B	3 LED LIGHT (Breakout WS2812B)	8.85	4.08
ASIN: B0007CM6GW	Photographic Film (Fuji Natura 1600 135-36)	16.47	2.00
Total		**503.38**	**204.88**

Table A.2: Cost and weight data for Project CODENAME.