Project CODENAME

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Contents

Part I

Introduction

List of Figures

List of Tables

4th Annual 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 challenged over 30 teams to submit a grant proposal for a high altitude balloon payload. This payload will be attached to a helium propelled weather balloon and lifted off into the atmosphere, to a projected height of over 120,000ft. The payload must then return to the ground safely (via parachute.) The exact function of the payload is typically left up to individual teams, but general guidelines include taking sensor readings of the atmosphere and/or aerial photographs. 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 of the High Altitude Challenge.
6. 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.)

The payload designed by Team CODENAME won first place in the competition and was awarded a $3,000 grant to build the payload according to the specifications described in this document.

Component Summary

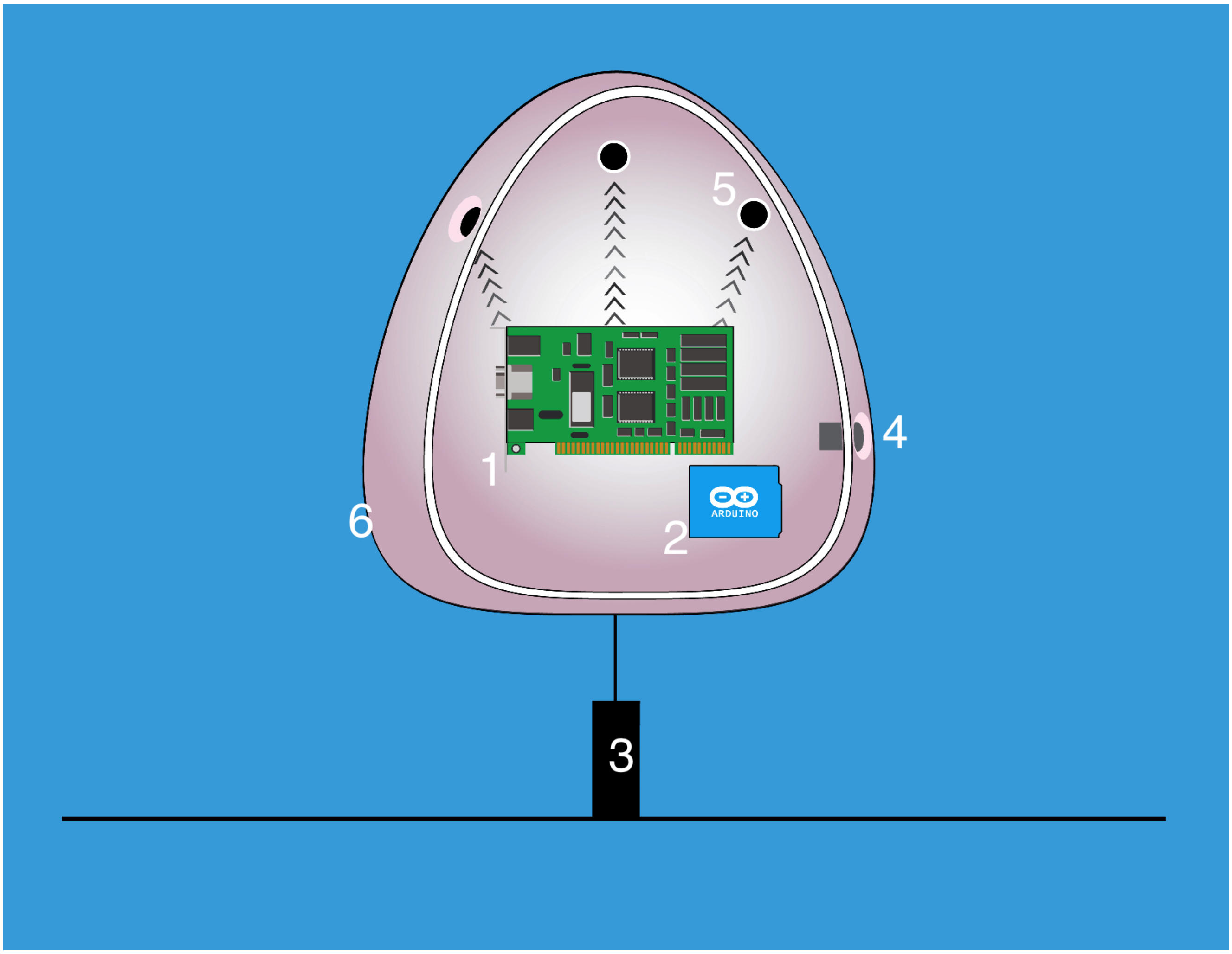

Figure 1: Cross-section of payload

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 in internal storage. Eight hour projected battery life.

2. **Arduino Micro** Provides an interface between the Tracksoar and the Samsung Galaxy S4 Chipset, as well as collecting data from the payload's ozone sensor.

3. **Tracksoar APRS Transmitter** Leverages existing radio relays to keep payload in constant contact after takeoff; sends all sensor data to ground station in real-time. Also equipped with GPS capable of high altitude positioning, along with external temperature and pressure sensors. Twelve hour projected battery life, does not require other computing components to function.

4. **External Cameras** 2MP and 15MP photographs taken for the duration of the flight.

5. **Additional Sensors** Sixteen distinct sensors (only three diagrammed here). These are discussed further further in Part II.

6. **Foamular 150** Insulating outer shell. Lightweight and impact resistant.

Not pictured: Parachute and balloon.

Flight Path

The target landing area for the payload is the Badlands National Park; the launch window will open in the first weeks of April, 2017, due to weather concerns. Project CODENAME will use the HabHub[1] predictive engine to determine more exact launch times. This predictive engine provides accurate predictions of likely flight paths up to 180 hours into the future. The following variables are required to generate accurate predictions:

Launch Point (lat long) 44.075604, -103.286696 (Stevens High School Football Field)

Launch Point Elevation 1043.2 m or 3422.5 feet

Burst Altitude 39060m*

Ascent Rate 3.83$\frac{\text{m}}{\text{s}}$*

Descent Rate 4.5658$\frac{\text{m}}{\text{s}}$*

*Determined by helium volume and balloon size, positive lift, and parachute size, respectively. These items are discussed in depth in Part III.

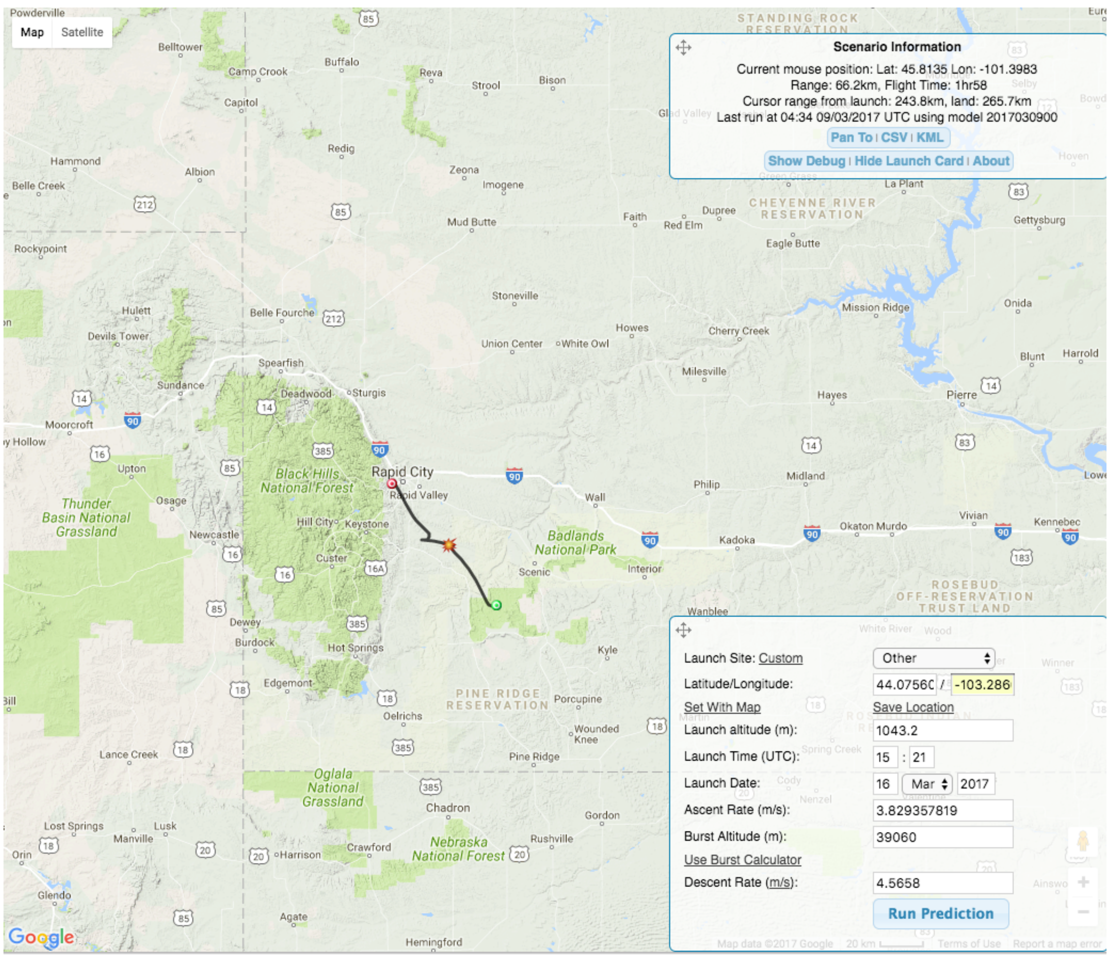

Figure 2: Example HabHub flight path prediction map for March 18, 2017.

Part II

Internal Components and Software

Project CODENAME has developed two important operational scripts: one runs on the S4 Chipset and is essentially a highly persistent app that commandeers the phone's onboard sensors and camera; the second is a modification to 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. The chipset contains eight integrated sensors, including a RGB light sensor, a magnetometer, a gravimeter, an accelerometer, thermometer, barometer, hygrometer, and sensors to measure orientation vectors. 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. Additionally, 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. These cameras are removed from the board and reattached with longer wires to optimize their viewing positions. All sensor data collected by the other two computing components (described below) are written to the S4's internal storage, which can be read after the payload returns to the ground. An extended lithium-ion battery (5200mAh) provides a projected eight hours of battery life under ideal operating conditions.

The script roots the S4 chipset to maximize utility, reduce unwanted phone operations and increase battery life.

Figure 3: A Samsung Galaxy S4 Chipset being removed from the rest of the phone.

Tracksoar APRS Transmitter

The Tracksoar APRS transmitter is the third and final 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 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. This allows for constant monitoring of the payload's position and exact conditions. The Tracksoar also has an independent power source projected to last up to 12 hours; this ensure that even if the rest of the payload loses power the capsule will continue transmitting its location. The Tracksoar is connected to the Arduino micro via the I^2C port.

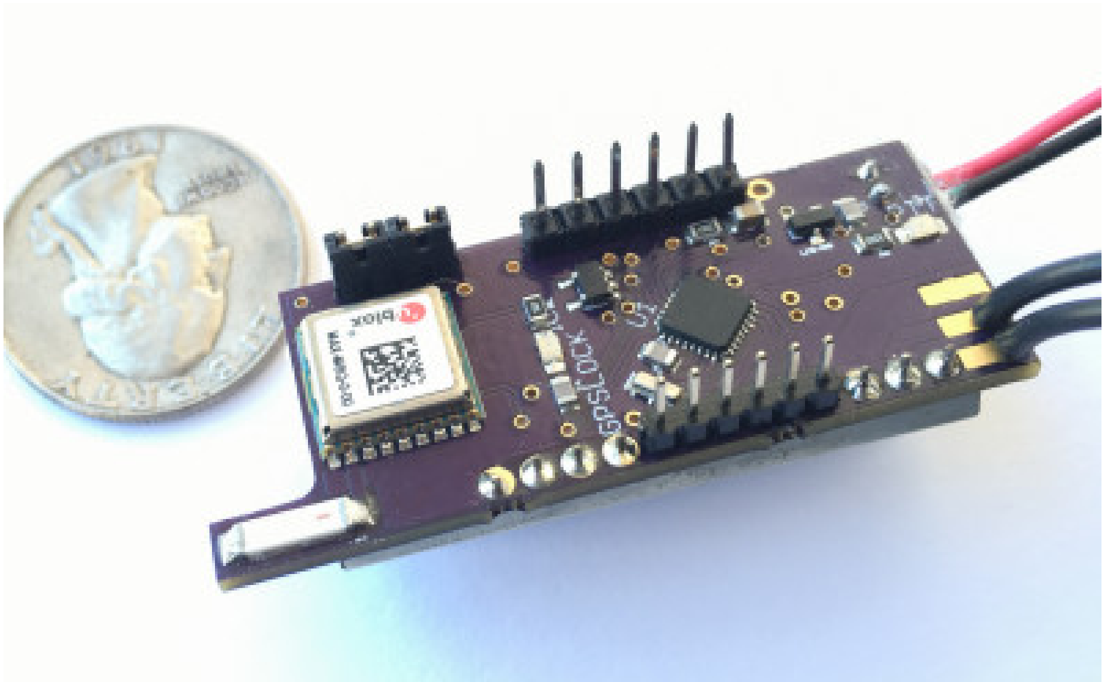

Figure 4: A Tracksoar APRS Tracking Device shown alongside quarter for scale. Antenna and battery not pictured.

Sensors

While the High Altitude Challenge requires only four sensors (internal and external temperature and pressure), the project CODENAME payload is 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.

- **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. It also improves location accuracy as it can be used to measure payload flight trajectory over short distances between GPS measurements. 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 to the capture of unique scientific data.

- **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, 5 of the High Altitude Challenge.
- **Gravimeter:** Measures strength of earth's gravitational field at a given altitude.
- **Magnetometer:** Measures strength of earth's magnetic field at a given altitude.

Figure 5: BMP-180 Sensor used by Tracksoar to measure temperature and pressure.

Part III

External

Housing

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.

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.

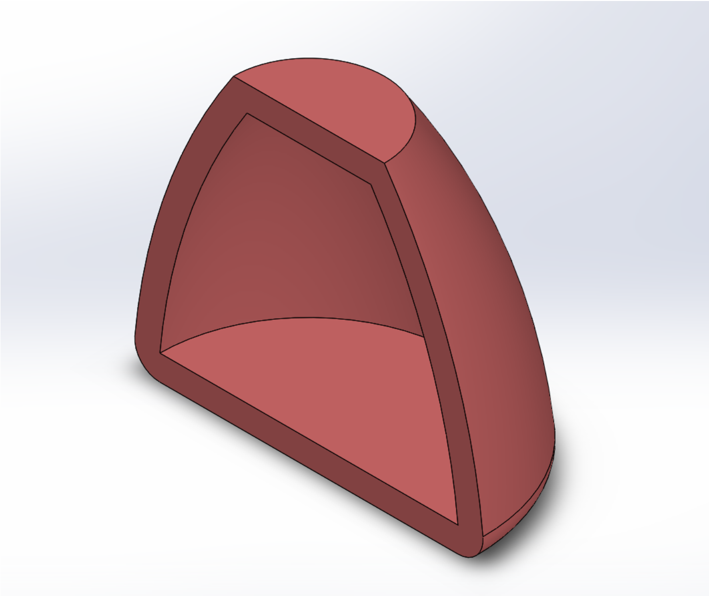

Figure 6: Rendering of Payload External Shape

Balloon and Helium

Past teams in the High Altitude Challenge have typically used 1200 gram weather balloons; however, Project CODENAME has selected a larger 1500 gram weather balloon. This increase in size will allow the payload to travel higher in a shorter amount of time, though it will increase the helium demand. See Table A in the appendix for a comparison of the standard weather balloon sizes[2].

Calculations 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 7.

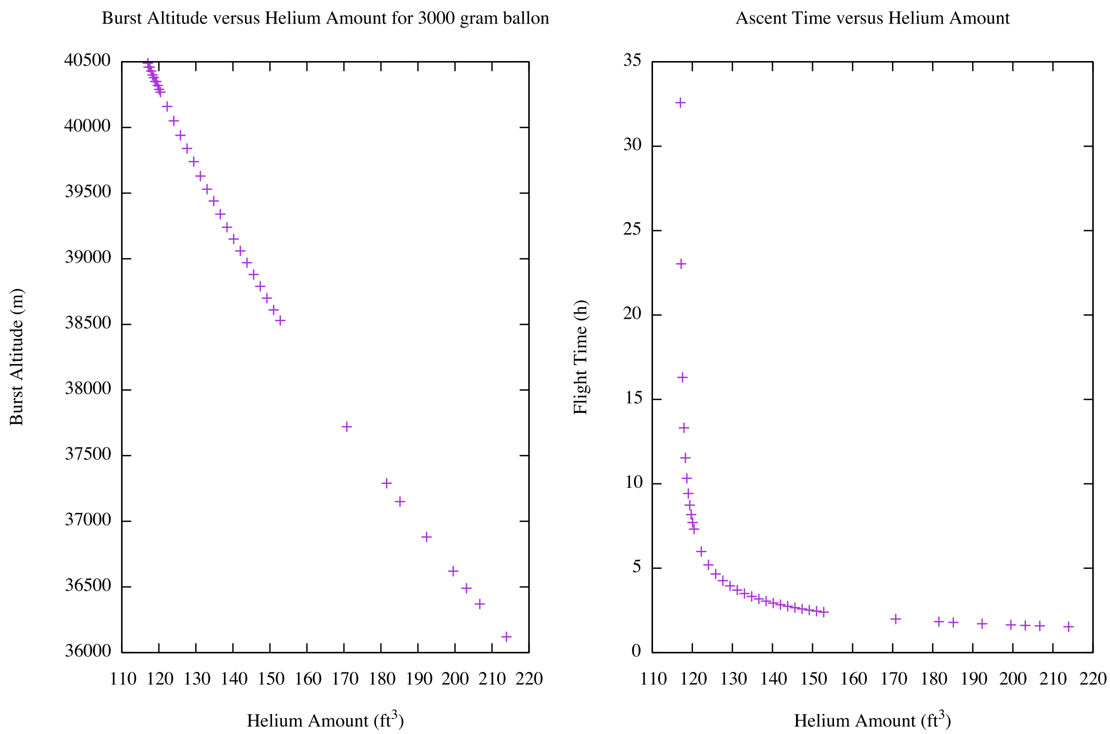

Figure 7: Graphs of ascent time and burst altitude, respectively, versus amount of helium.

Parachute

The following equation[3] 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

$r = 1.22\frac{\mathrm{kg}}{\mathrm{m}^3}$ (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[4] suggested that payload's impact-resistant shell would allow it to land at speeds between $3\frac{\mathrm{m}}{\mathrm{s}}$ and $5\frac{\mathrm{m}}{\mathrm{s}}$ without sustaining major internal damage. Solving equation 1 for each of these velocities provides the range for the ideal diameter of Project CODENAME's parachute (assuming mass to be 250 grams).

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

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

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

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

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

The parachute was tested in a droptest 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 8. Since the slope is a constant $1.426\frac{\mathrm{m}}{\mathrm{s}}$, this was taken to be the terminal velocity of the parachute.

Unfortunately, during the flight of Project CODENAME, the parachute never deployed. This was a result of the 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 damage.

The outside of the parachute was painted in phosphorescent paint; This 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.

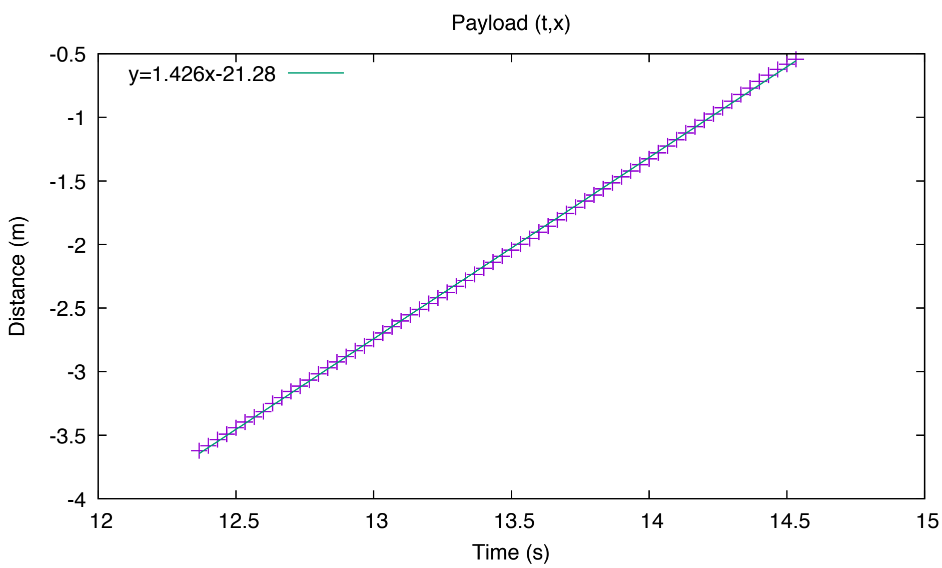

Figure 8: Position-time graph showing terminal velocity of TARC-16 parachute and dummy payload.

Part IV

Data Collected

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

Bibliography

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

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

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

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

Appendices

Appendix A

Table Data

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 2: Cost and weight data for Project CODENAME.

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

Appendix A

Tracksoar Data

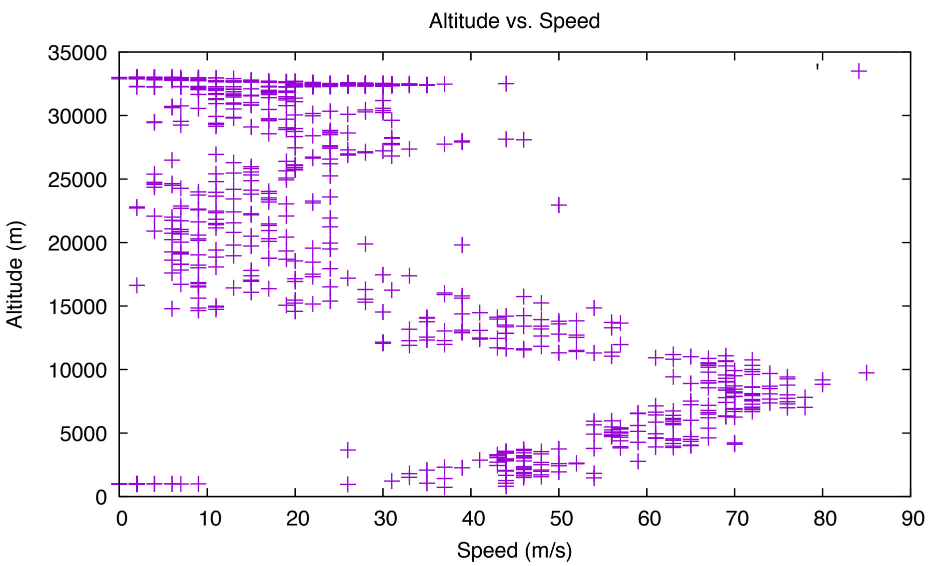

Figure A.1:

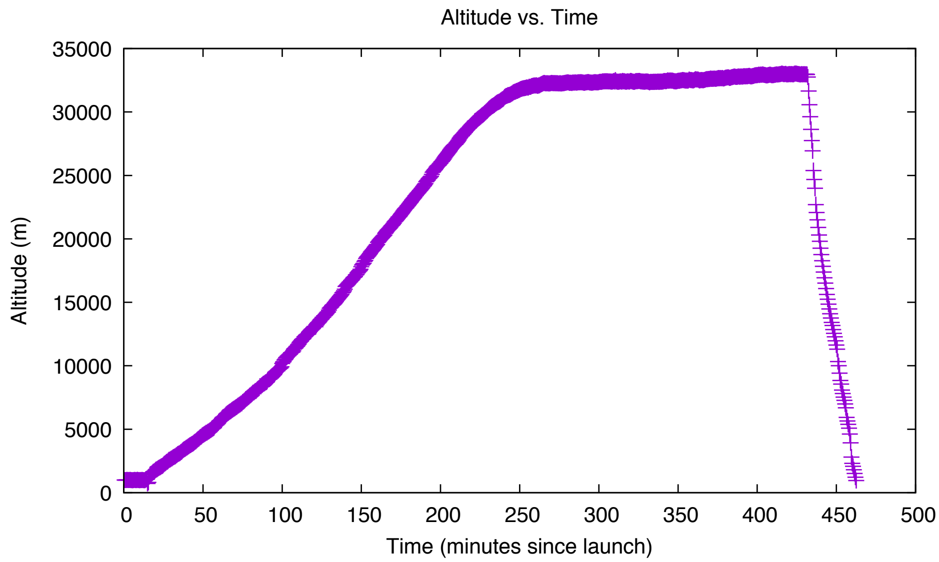

Figure A.2:

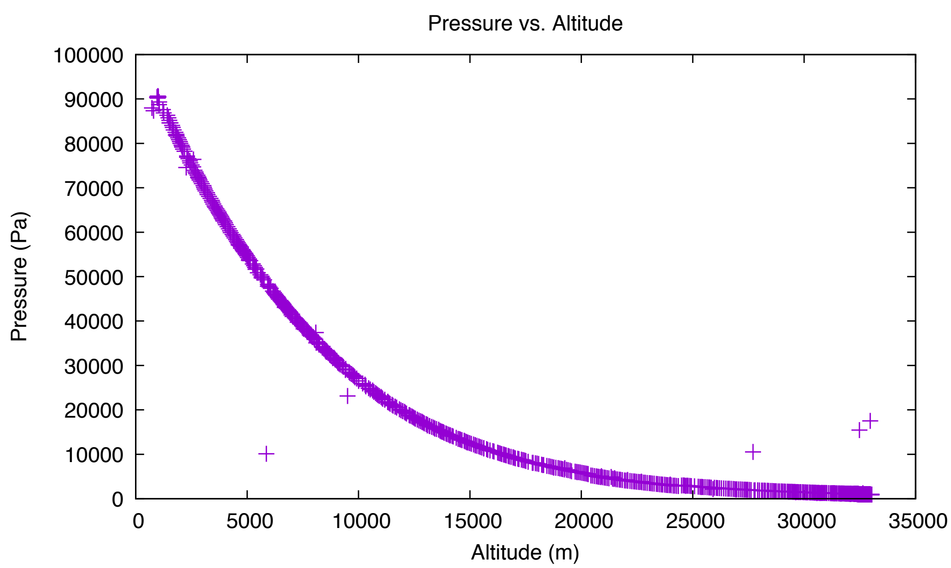

Figure A.3:

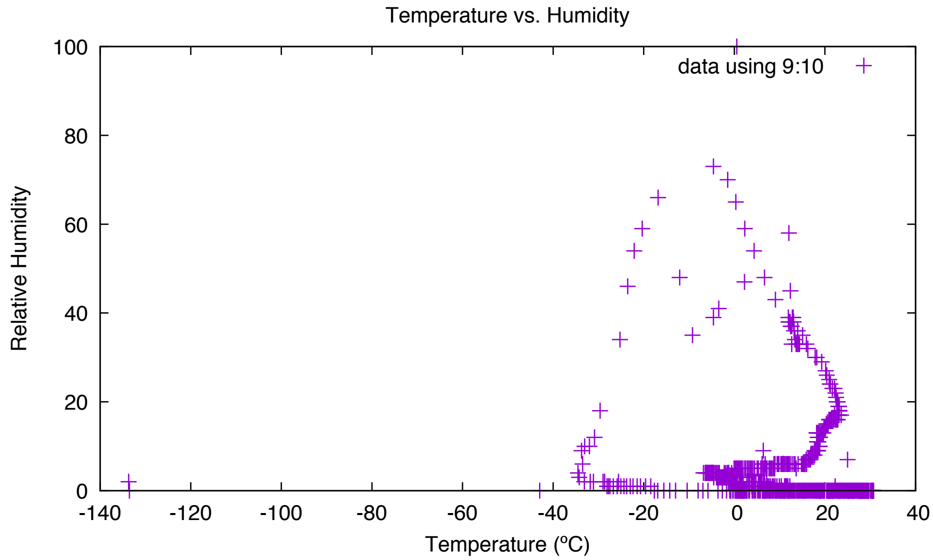

Figure A.4:

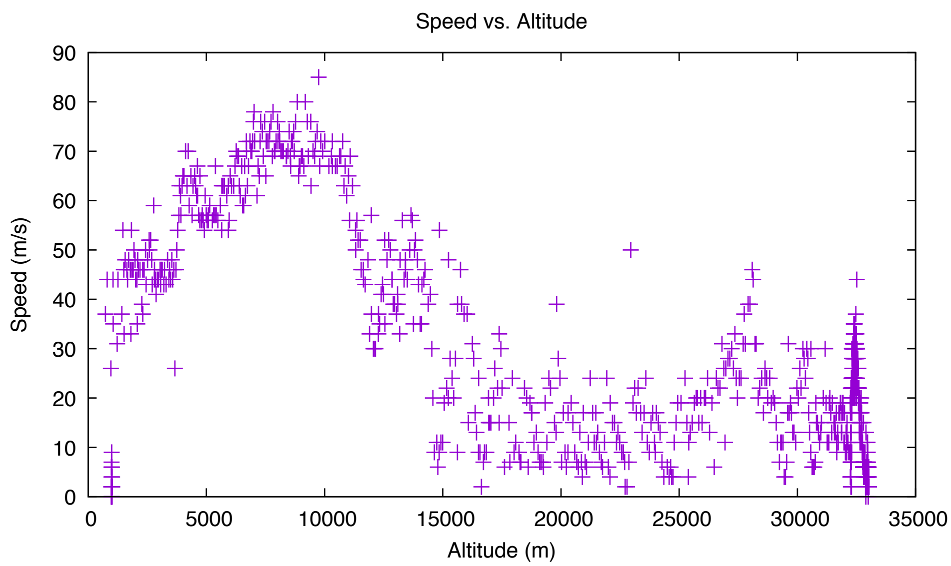

Figure A.5:

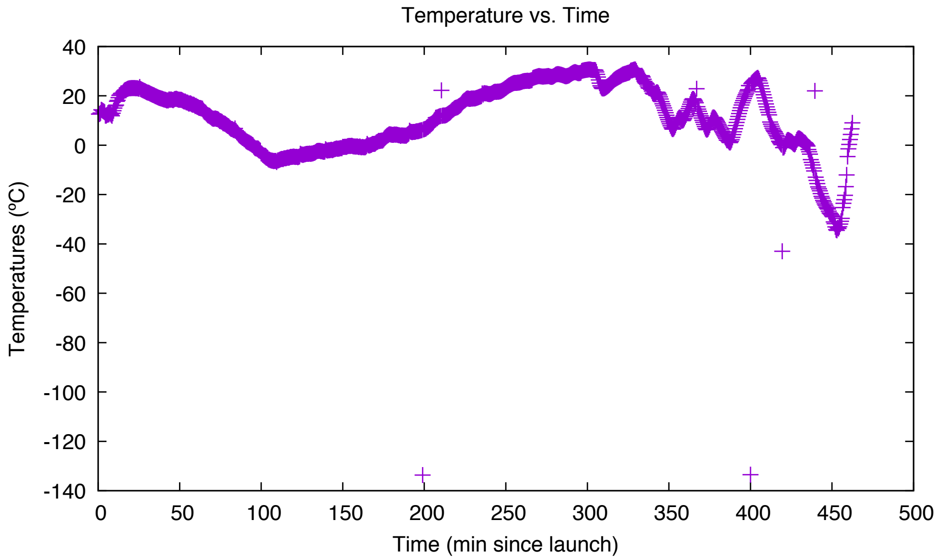
Temperature vs. Time
Temperatures (ºC)
Time (min since launch)
40
20
0
-20
-40
-60
-80
-100
-120
-140
0
50
100
150
200
250
300
350
400
450
500

Figure A.6: