Project CODENAME

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Part I

Introduction

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.

Part II

Path Prediction, Tracking, and Recovery

Flight Path Prediction

The target landing area for the payload was the 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 II 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 designed through the collaborative efforts of Gabriel Spahn and Joshua Morin-Baxter, based on work done by Penny Zabel. The GOSH Flight Path predictor allows an hour-by-hour analysis of every possible flight path within a three day window. See Figure II for a better idea of what this means.

Both flight path predictors rely on the following information to provide 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 $3.83\frac{\mathrm{m}}{\mathrm{s}}$*

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

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

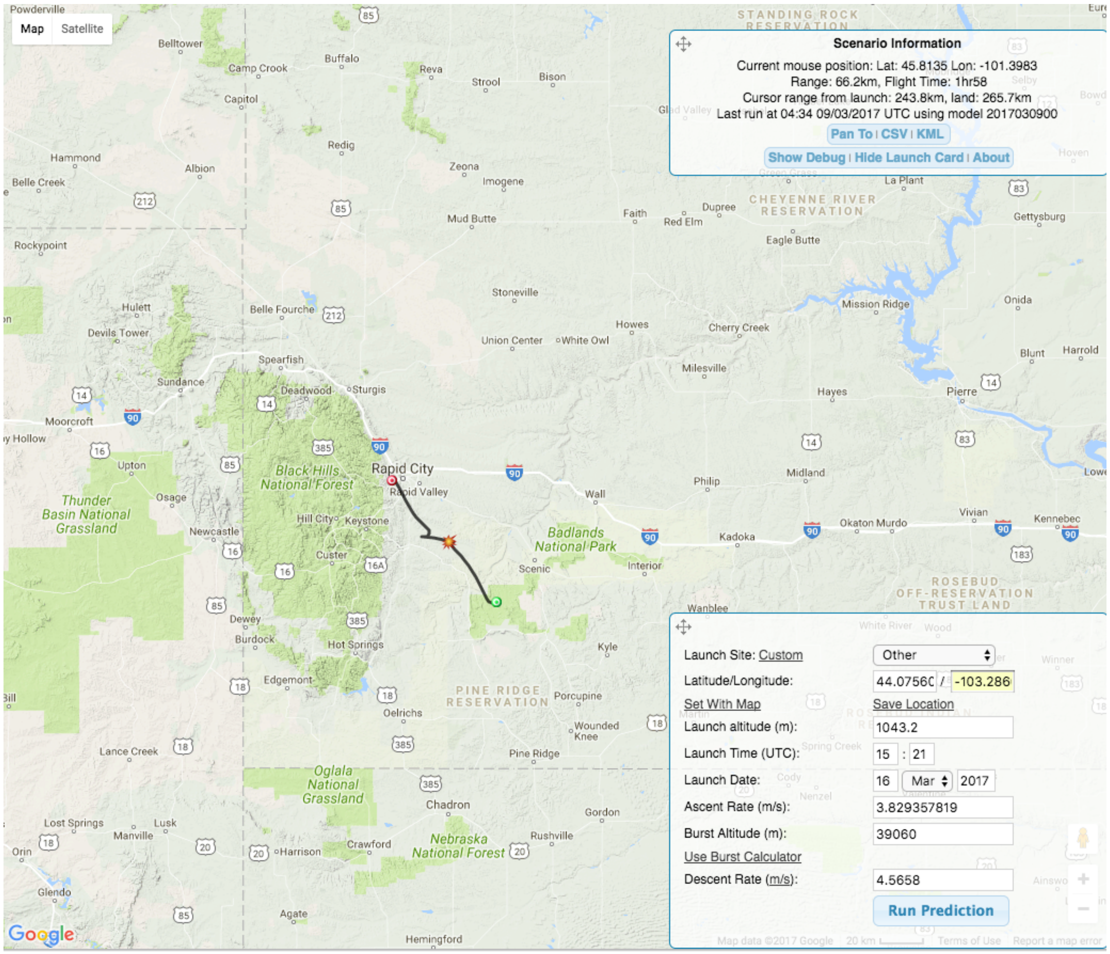

Figure 1: Example HabHub flight path prediction map for March 18, 2017.

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 volume	98.86357216		
5	21	17		mass (kg)	1.750		
Launch Point	44.055223	-103.203584		drag coefficient	0.5		
Target Point 1	43.973828	-102.332969		burst altitude (m)	35240		
Target Point 2	43.647654	-102.763701		terminal velocity (m/s)	4.5658		
				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**
05/19 at 15:00	170519/1500	1.61625918	44.3103291	-103.3175522	Google Maps	54.071	53.429	18.50858467
05/19 at 16:00	170519/1600	1.616928978	44.322354	-103.3120856	Google Maps	54.186	54.003	19.22382435
05/19 at 17:00	170519/1700	1.616874165	44.3221693	-103.276612	Google Maps	52.611	53.124	18.79570991
05/19 at 18:00	170519/1800	1.616747308	44.3267733	-103.2614799	Google Maps	52.091	53.048	18.98027557
05/19 at 19:00	170519/1900	1.617071202	44.3417986	-103.2223741	Google Maps	50.892	53.104	19.82231922
05/19 at 20:00	170519/2000	1.617572841	44.3576011	-103.1329786	Google Maps	47.699	52.373	21.18293769
05/19 at 21:00	170519/2100	1.618576335	44.3879427	-102.929679	Google Maps	41.144	51.810	26.69122274
05/19 at 22:00	170519/2200	1.620260212	44.3711711	-103.0071889	Google Maps	43.244	51.434	23.89850294
05/19 at 23:00	170519/2300	1.620924397	44.3506417	-103.0717732	Google Maps	44.931	50.928	21.43015698
05/20 at 00:00	170520/0000	1.621904576	44.3121281	-103.0970987	Google Maps	44.517	48.811	18.51794548
05/20 at 01:00	170520/0100	1.621807631	44.3248595	-103.0767479	Google Maps	44.135	49.310	19.66124896
05/20 at 02:00	170520/0200	1.621716935	44.318119	-103.1096641	Google Maps	45.263	49.415	18.75090538
05/20 at 03:00	170520/0300	1.62144272	44.275776	-103.1717288	Google Maps	46.538	47.909	15.32030437
05/20 at 04:00	170520/0400	1.620912422	44.2459647	-103.2053149	Google Maps	47.184	46.814	13.17925409
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05/20 at 06:00	170520/0600	1.620571246	44.2264735	-103.1951953	Google Maps	46.206	45.390	11.83956791
05/20 at 07:00	170520/0700	1.621012197	44.2170497	-103.2058827	Google Maps	46.461	45.076	11.18172468
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05/20 at 15:00	170520/1500	1.620934767	43.9499565	-103.1535142	Google Maps	40.842	28.534	7.687125553
05/20 at 16:00	170520/1600	1.622952873	43.9249048	-103.1284665	Google Maps	39.715	26.420	9.747689807
05/20 at 17:00	170520/1700	1.625094212	43.902823	-103.092155	Google Maps	38.089	24.070	11.89833057
05/20 at 18:00	170520/1800	1.627846918	43.8802113	-103.0417898	Google Maps	35.861	21.231	14.52426686
05/20 at 19:00	170520/1900	1.629907629	43.8667782	-102.9682186	Google Maps	32.469	18.259	17.50859008
05/20 at 20:00	170520/2000	1.631271435	43.8595568	-102.8884493	Google Maps	28.752	15.910	20.69879878
05/20 at 21:00	170520/2100	1.632513656	43.8575218	-102.8330796	Google Maps	26.157	14.908	22.93876802
05/20 at 22:00	170520/2200	1.633833839	43.8638981	-102.780174	Google Maps	23.517	14.964	24.8637518
05/20 at 23:00	170520/2300	1.635271373	43.8616917	-102.7406727	Google Maps	21.720	14.833	26.62483883
05/21 at 00:00	170521/0000	1.635807229	43.845685	-102.7102999	Google Maps	20.765	13.940	28.4900902
05/21 at 01:00	170521/0100	1.635666519	43.8108327	-102.6907872	Google Maps	21.077	11.848	30.59682394
05/21 at 02:00	170521/0200	1.635322945	43.7732688	-102.6697376	Google Maps	21.757	9.867	32.94756943
05/21 at 03:00	170521/0300	1.634276381	43.7474473	-102.6506668	Google Maps	22.252	8.912	34.78375207
05/21 at 04:00	170521/0400	1.631939834	43.7389252	-102.6310123	Google Maps	21.998	9.149	35.91990586
05/21 at 05:00	170521/0500	1.630330546	43.7449776	-102.5965395	Google Maps	20.553	10.721	37.05188965
05/21 at 06:00	170521/0600	1.629538923	43.752741	-102.5591631	Google Maps	18.982	12.534	38.28750798
05/21 at 07:00	170521/0700	1.629232245	43.7639692	-102.5181594	Google Maps	17.185	14.663	39.61087541
05/21 at 08:00	170521/0800	1.629924023	43.765562	-102.4759664	Google Maps	16.056	16.520	41.37985258
05/21 at 09:00	170521/0900	1.631762151	43.7659011	-102.4334659	Google Maps	15.213	18.407	43.23262794
05/21 at 10:00	170521/1000	1.634123027	43.7743702	-102.3985702	Google Maps	14.163	20.229	44.51925728
05/21 at 11:00	170521/1100	*1.635111326*	43.7823518	-102.3824659	Google Maps	13.457	21.192	45.00573838
05/21 at 12:00	170521/1200	1.63466751	43.7894008	-102.3932801	Google Maps	13.092	20.930	44.31136739
05/21 at 13:00	170521/1300	1.634918547	43.7983391	-102.4237763	Google Maps	12.941	19.912	42.67163332
05/21 at 14:00	170521/1400	1.63417435	43.8073504	-102.4642162	Google Maps	13.229	18.583	40.58100708
05/21 at 15:00	170521/1500	1.636843335	43.823499	-102.4832718	Google Maps	12.802	18.537	39.25085209
05/21 at 16:00	170521/1600	1.63857087	43.8507289	-102.4776097	Google Maps	11.143	20.019	38.77625796
05/21 at 17:00	170521/1700	1.640202469	43.880797	-102.4468527	Google Maps	8.569	22.571	39.51355253
05/21 at 18:00	170521/1800	1.642002889	43.8984777	-102.3929403	Google Maps	6.001	25.348	41.73541359
05/21 at 19:00	170521/1900	1.643507162	43.8999662	-102.3499986	Google Maps	5.173	27.017	43.77502404
05/21 at 20:00	170521/2000	1.645184586	43.8879606	-102.3507775	Google Maps	5.999	26.461	43.95241095
05/21 at 21:00	170521/2100	1.646330397	43.8888694	-102.3888055	Google Maps	6.494	25.053	42.1134743
05/21 at 22:00	170521/2200	1.6395291	43.8947293	-102.3969722	Google Maps	6.325	25.024	41.61133528
05/21 at 23:00	170521/2300	1.631284848	43.8307834	-102.3585768	Google Maps	9.965	23.856	44.8072216
05/22 at 00:00	170522/0000	1.633342002	43.7930648	-102.3483218	Google Maps	12.513	23.047	46.25586709
05/22 at 01:00	170522/0100	1.636580431	43.7609614	-102.3006766	Google Maps	14.795	24.416	49.32969875
05/22 at 02:00	170522/0200	1.639878219	43.7388621	-102.3378178	Google Maps	16.236	22.190	48.3296655
05/22 at 03:00	170522/0300	1.642302214	43.7244116	-102.3933525	Google Maps	17.494	19.249	46.36898345

Figure 2: Example Prediction using GOSH Flight Path Predictor

Part III

Internal Components and Software

Internal Component Summary

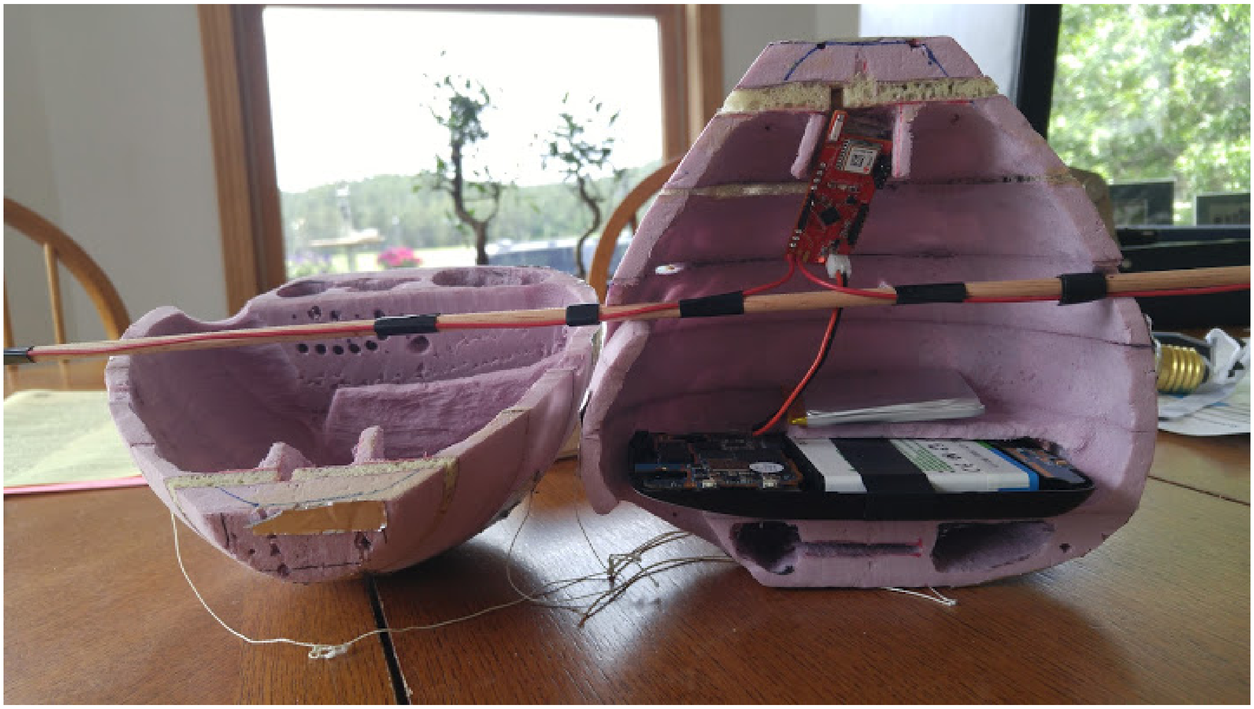

Figure 3: Cross-section of payload

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** Extended lithium-ion battery. 5200mAh.
3. **Chipset Camera** 16 MP Camera, pointed toward the ground.
4. **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.
5. **Tracksoar Battery** High durability lithium-ion battery. Powered the Tracksoar for 40 hours uninterrupted during ground tests.
6. **Tracksoar Antenna** Antenna
7. **Foamular 150** Insulating outer shell. Lightweight and impact resistant.

Not pictured: Parachute and balloon.

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. See Figure III. 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. Project CODENAME has further configured the chipset to write data to an external SD card as a failsafe.

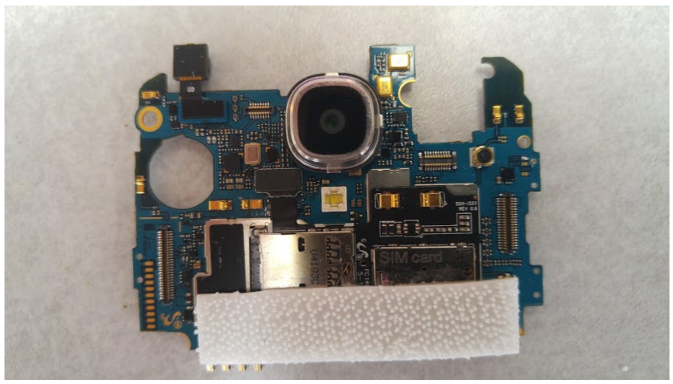

Figure 4: Chipset alone; note that the RGB light sensor and LED indicator are missing as they were lost on impact

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 349 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 5: Photograph taken by rear camera on Galaxy S4 Chipset

Power Supply and Battery Life The Galaxy Samsung S4 Phone 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 5600mAh. During ground tests, the chipset ran between 6 and 8 hours on a single charge. During the flight, the chipset powered down with 40% battery remaining. While the cause is not entirely understood, it is believed to be related to overheating. (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. All other phone components were removed.

Figure 6: 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.

When running at room temperature (and often when refrigerated as well) the chipset had a tendency to overheat to the point of shutting down. This issue stemmed from the excessive camera use required by the program and was exacerbated by the larger battery and plastic tray. To solve this, Project CODENAMe made a number of minor adjustments to the programming to maintain optimal temperature conditions.

Figure 7: 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 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 three 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 error that finally resulted in a critical failure of the entire device. The second device had the same error, which was finally determined to be a wiring issue on the motherboard. Finally, a third Tracksoar was acquired that did NOT have this issue. However, programming on this third computing component revealed a critical flaw in the official source code that resulted in the Tracksoar freezing and becoming inoperable after random intervals of time. Project CODENAME fixed this error by leveraging the existing watchdog timer on the ATMEGA328P. The working version of the source code is available on Project CODENAME's Github.

Following the changes to the source code, the Tracksoar performed admirably for the entire flight and even continued transmitting after it was recovered on the ground.

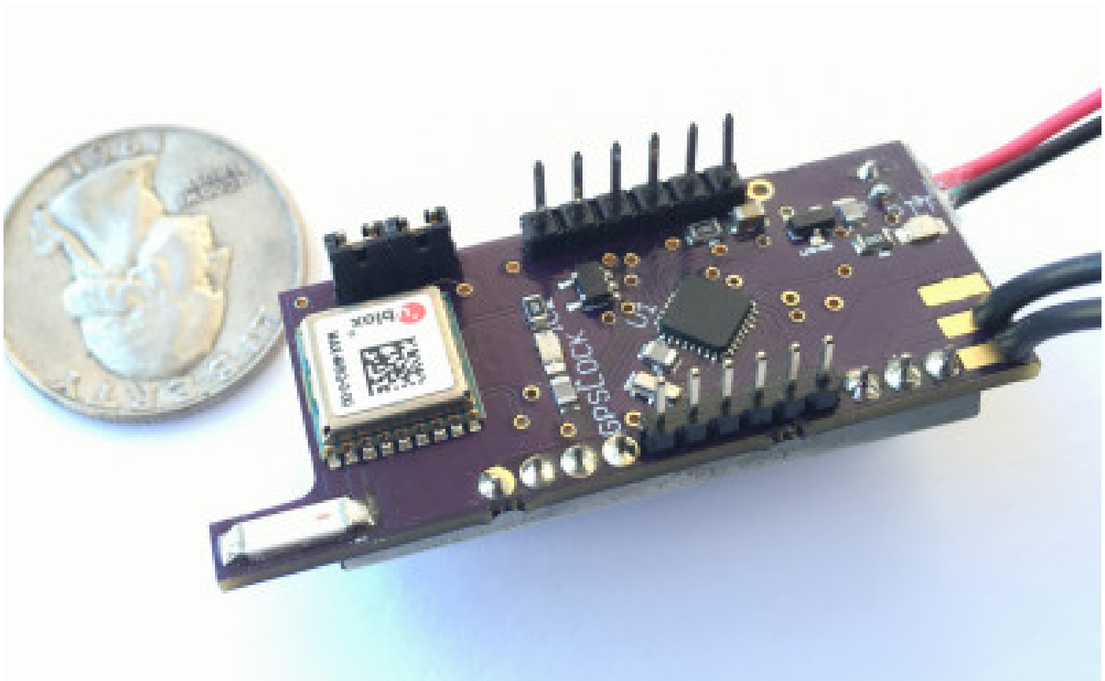

Figure 8: A Tracksoar APRS Tracking Device shown alongside quarter for scale. Antenna and battery not pictured.

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

Part IV

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.

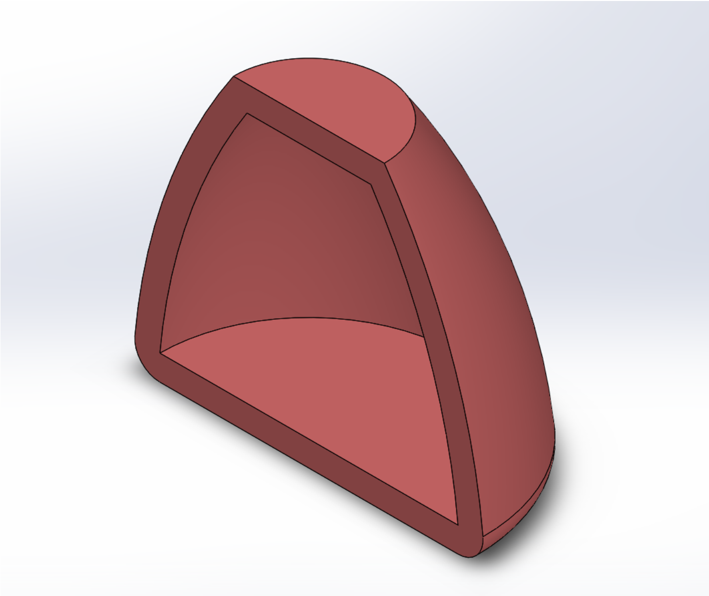

Figure 10: Rendering of Payload External Shape

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].

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 11.

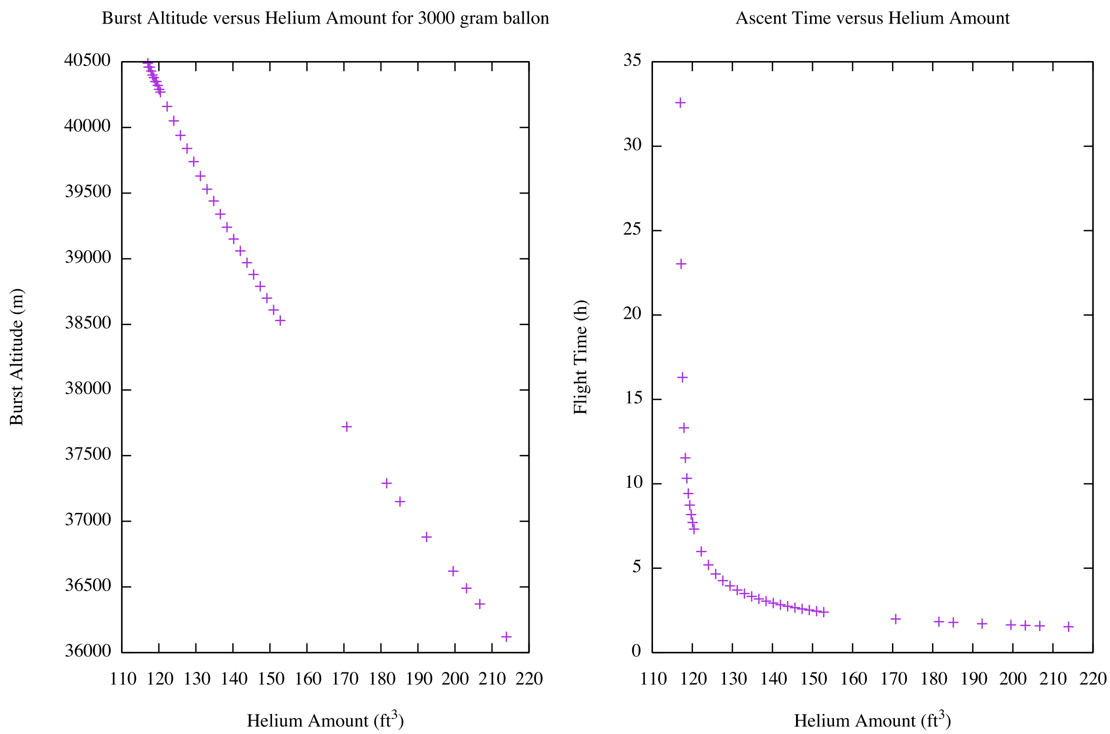

Figure 11: Graphs of ascent time and burst altitude, respectively, versus amount of helium.

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 12. 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.

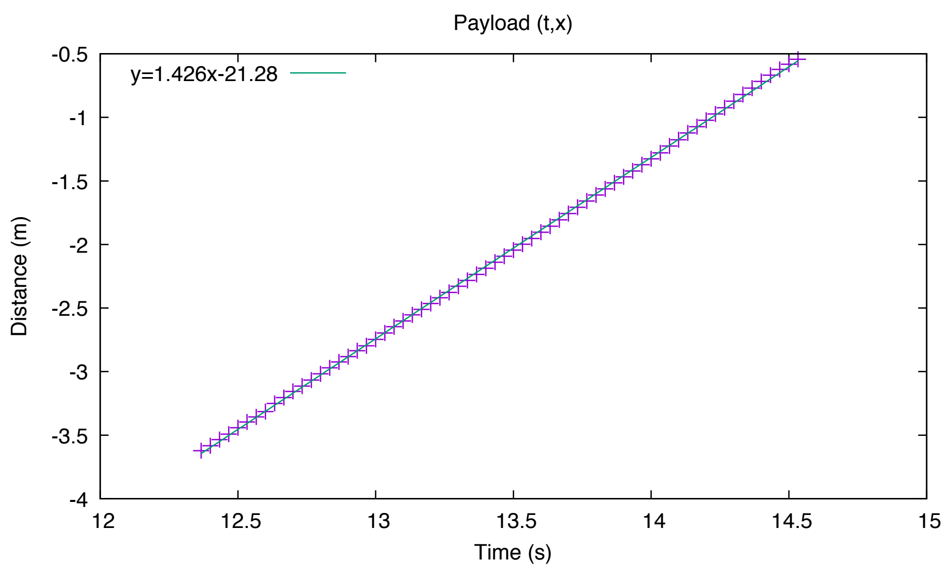

Figure 12: Position-time graph showing terminal velocity of TARC-16 parachute and dummy payload.

Part V

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 $\frac{\mathrm{m}}{\mathrm{s}}$	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

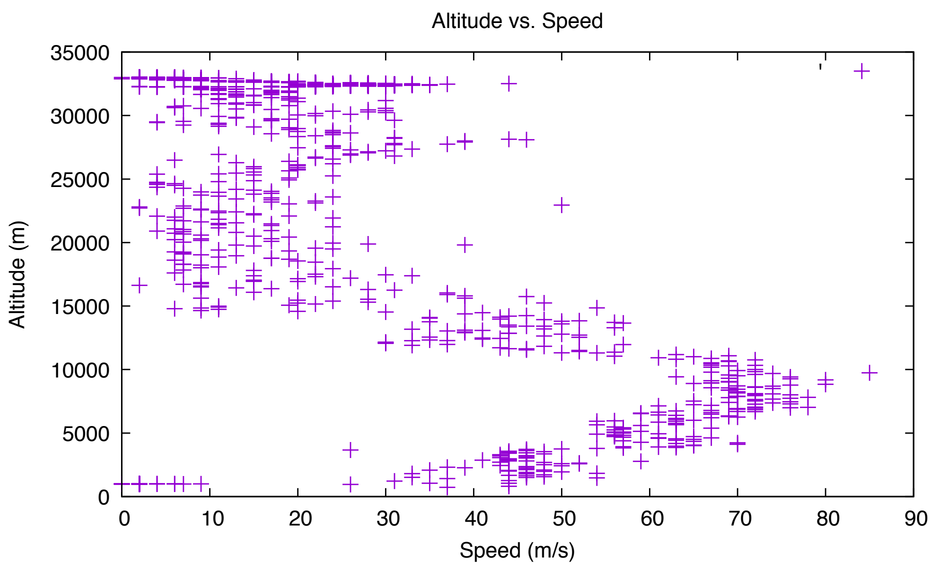

Figure A.1:

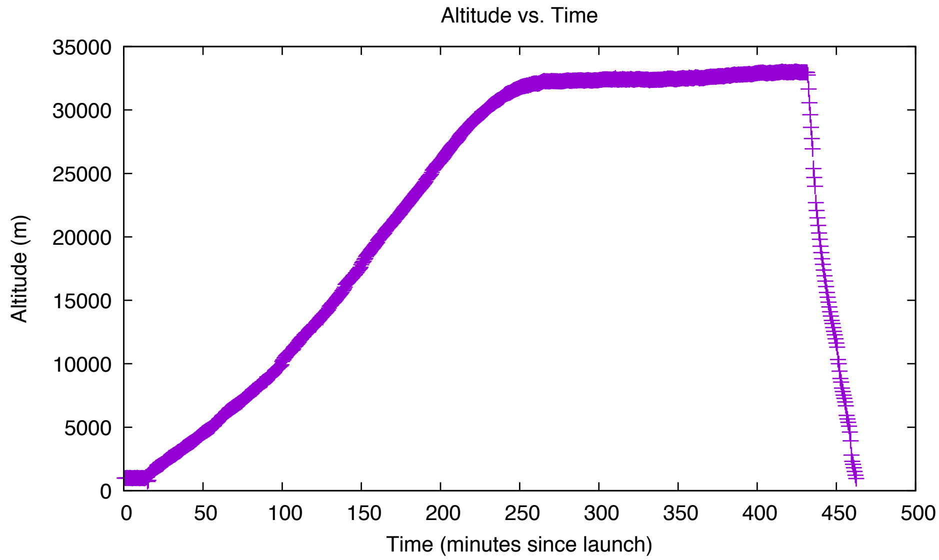

Figure A.2:

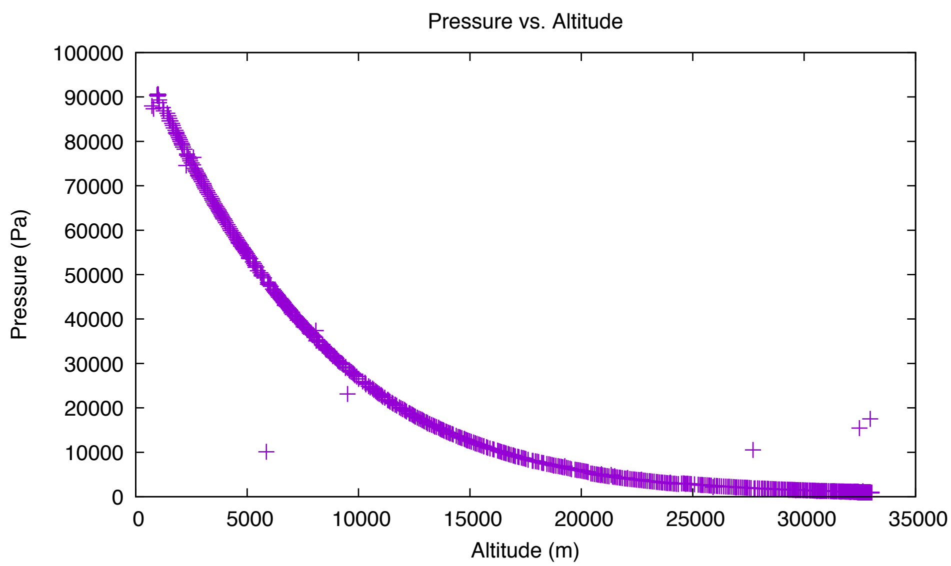

Figure A.3:

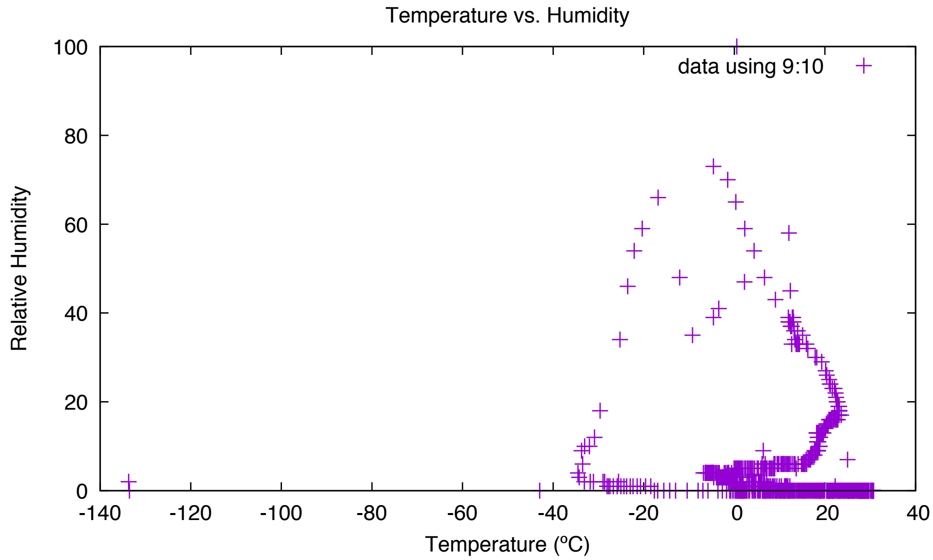

Figure A.4:

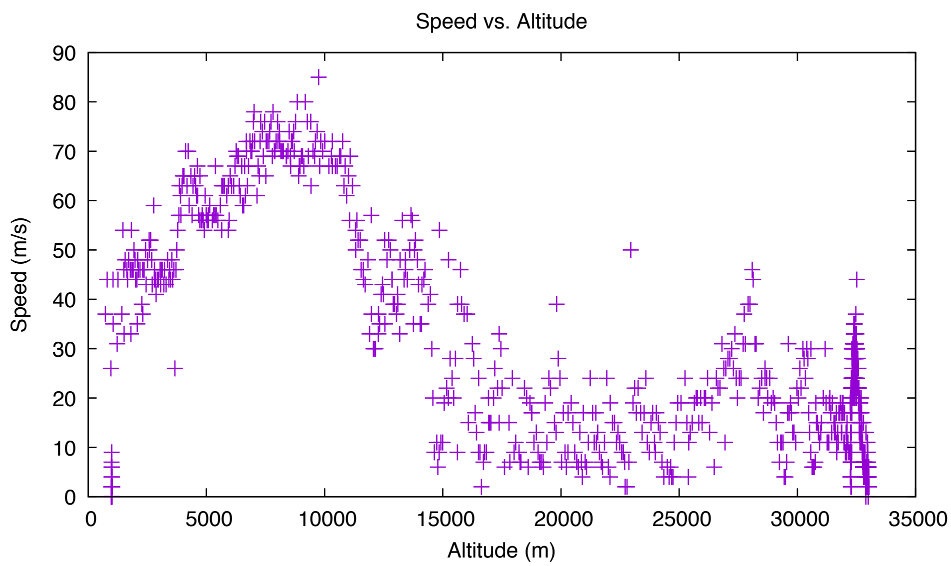

Figure A.5:

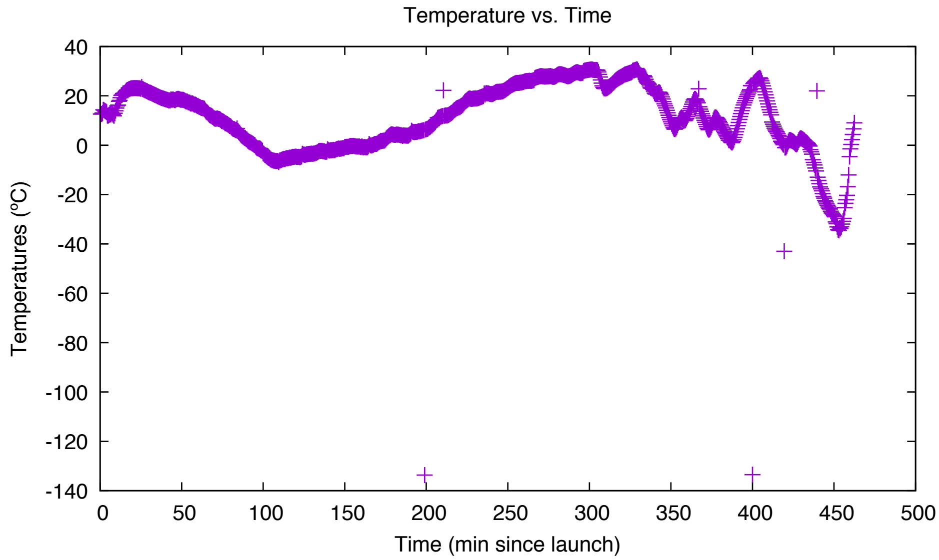
Temperature vs. Time
Temperatures (ºC)
40
20
0
-20
-40
-60
-80
-100
-120
-140
0
50
100
150
200
250
300
350
400
450
500
Time (min since launch)

Figure A.6: