DEMOSat 2011
DESIGN DOCUMENT

Team Skyhawk

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1.0 Mission Overview

Team Skyhawk has four objectives for its 2011 BallonSat project. The first is monitoring and recording gamma and beta radiation levels during the flight. The second is monitoring and recording system performance. The third is building a reusable skeletal structure for future flights. The fourth is recording video of the flight.

Due to the Fukushima nuclear disaster radiation is, once again, a hot research area. As such, the team plans to measure radiation throughout the flight with Geiger tubes that detect both beta and gamma radiation. The team hopes to determine what current radiation levels are as a function of altitude. The team will compare this data with historical information to see if there is a noticeable increase in radiation levels over Colorado.

Monitoring system performance creates an opportunity for improving of future DemoSats. Monitoring heaters, for example, allows for better understanding of size and power requirements. Monitoring acceleration and compass heading gives a better understanding of flight behavior. Monitoring current draw allows for using the smallest batteries capable of operating for the full flight.

In past BallonSat years, each team has built its own shell from scratch. While this adds flexibility, it is time consuming and inefficient. This team hopes to create a skeleton which future teams can easily reuse. This allows for reduced development time and costs. The key is to create a light-weight skeleton with a lot of mounting options.

The video is mostly for fun but also give visual recordings of flight behavior. This can facilitate understanding sensor readings and serves as a backup in case main sensors fail.

2.0 Requirements Flow Down

The top level requirements of this payload are to record radiation, monitor system performance, test the new skeleton and record video. Each of these systems has an extensive list of requirements.

Radiation Monitoring

Level 0: Design & Fabricate Radiation Monitoring System

Level 1: Hardware
   i) Design, build and test high-voltage power system.
   ii) Design, build and test counter system.
   iii) Purchase and test Geiger tubes.
   iv) Purchase data recording device.

Level 1: Software
   i) Write and test code for storing counts.
System Monitoring
Level 0: Design & Fabricate System Monitor
Level 1: Hardware
   i) Determine needs.
   ii) Select and purchase sensor monitoring and recording controller.
   iii) Select and purchase sensors.
      (1) Temperature
      (2) Compass
      (3) Accelerometer
      (4) GPS
      (5) Current monitor
   iv) Design and build current monitoring system.
   v) Design and build heating array.
Level 1: Software.
   i) Write and test data logging software.
   ii) Write and test sensor code.
      (1) Temperature
      (2) Compass
      (3) Accelerometer
      (4) GPS
      (5) Current monitor
   iii) Write ant test heater code.

Skeleton
Level 0: Design & Fabricate Skeleton.
Level 1: Determine size requirements.
   i) Determine number and size of electronic components to be installed.
Level 1: Select shape.
   (1) Endoskeleton or exoskeleton.
   (2) Incorporate flight string guide.
   (3) Locate mounting points for hardware.
Level 1: Select material.
   (1) Weight vs. rigidity.
Level 1: Build & test prototype.

Video
Level 0: Design & Fabricate Camera System.
Level 1: Hardware.
   i) Determine needs and select cameras.
   ii) Determine operating methods.
      (1) Data storage
      (2) Power
      (3) Trigger
Level 1: Software
   i) Determine trigger points.
   ii) Write and test operating software.
3.0 Design

BallonSat missions require all components be small, durable, efficient and light weight. They must also fit within a $1000 budget. Each component will reflect these constraints.

The Geiger system had two parts one being the high voltage power supply running to the 5 individual Geiger tubes and the other being the counting circuit running to the Arduino UNO. The high voltage supply produces 400 V and was salvaged from a previous launch. The supply will be placed in a box wrapped with foil to insulate it. This should prevent any disturbance of the other electronics in the payload. The Geiger counting system design is shown in Figure 1. It uses 470kΩ resistor and a 1uF electrolytic capacitor to reduce signal noise before reaching the counting circuit. An NPN transistor, which was also grounded by a 100kΩ resistor, raises the signal strength for the counter circuit.

![Figure 1: Geiger counting system with signal conditioning.](image-url)

The signal then goes to a Hex Schmitt Trigger which further cleans the signal. Then each signal goes to its own binary counter. Since the Arduino UNO had limited number of digital pins; three multiplexers are used to make a total of 8 Inputs and 3 Outputs rather than having 20 inputs and 2 Outputs as seen in Figure 2.
The systems monitor requires a combination of digital and analog sensors as well as data logging capabilities. Each sensor has been carefully screened and selected. The digital sensors the team wishes to use are a compass, accelerometer, and GPS. The analog sensors are temperature and voltage monitors. Heaters will also be controlled by digital signals. Data will be gathered by an Arduino Mega 2560 and stored on an SDHC card via a GPSLogger shield from Adafruit.

The Arduino Mega 2560 was selected due to size, cost, weight and simplicity. The Mega was purchased off eBay for $36.80, weighs only 40 g, provides 14 analog pins and 54 digital in/out pins. It also has 256 KB of flash memory for program storage and three serial communication busses in case additional sensors are desired.

An Adafruit GPS Logger shield will provide GPS capabilities as well as data logging via an SD card slot. Code for the GPS and logging functions are readily available as is a help forum on Adafruit’s website. Some SDHC cards have also been reported to work, giving storage capabilities beyond the 2 gigabytes SD cards are capable of.

For a compass the team selected a CMPS10 tilt-compensated unit purchased from The Robot Shop. The team had experience with a more basic compass on a robot. When it tilted the heading changed and the robot got confused and changed heading. This tilt compensated unit will self-correct the heading within a few degrees for a more accurate representation of rotation angle. The compass can communicate with the microcontroller using I2C.

An ADXL345 16 g accelerometer breakout was purchased from SparkFun. The team hopes to capture the g-forces experienced during the balloon burst and parachute catching. Estimates placed this close to 16 g’s. The accelerometer is also capable of reading at lower levels for the remainder of the flight and using programmable interrupts for key events. It can also communicate using I2C on a shared bus with the compass.

A Lassen IQ GPS was selected due to it being able to function above 60,000 feet. Few units are capable of doing this due to security limitations. The IQ will also mount to the Adafruit GPS Logger shield. It uses a serial communication port for data transfer and outputs standard
NMEA GPS data including latitude, longitude, altitude and time, which are the team’s primary concerns.

Five TMP36 temperature sensors were selected for the unit. The TMP36 is capable of reading down to -40 °C and outputs readings as a linear voltage. It is also small, less than 1 g each and draws less than one hundredth of a milliamp. Each sensor requires one analog pin for data logging.

Voltage monitoring will be handled by series resistors and analog pins on the Mega. Analog pins are only capable of measuring up to five volts while the battery power will be over seven. The correct number of resistors will be combined to bring the value below the 5v threshold. Voltage will be monitored to either side of a 0.01 Ω resistor in-line with the power supply for components. This will be used to derive the current draw of each component.

The heaters controlled by the Mega will use MOSFET triggers. Temperature readings will be used to trigger the heaters on and off. The heaters will be 25-50 Ω ceramic resistors fed by the main battery.

The function block diagram for the system monitor is shown in Figure 3, the wiring schematic is shown in Figure 4: Arduino Mega wiring schematic. This includes heaters, a single current monitor and all other sensors.

![Function block diagram for the system monitor.](image-url)
The camera systems are controlled by a separate Arduino Pro board via a bank of npn transistors switching the necessary controls on the cameras. The transistors have a pull-down resistor on the input signal to ensure positive switching control. This system is powered by its own battery supply and controls its own heater system for all cameras and controls. See Figure 6.

The cameras themselves are 1280x960p HD 30 fps stand-alone units purchased from eBay for $24 ea. There are five in all; two oriented downwards, two oriented upwards with a staggered start for effective 60 fps rate to capture balloon rupture, and one camera oriented to the side to capture the vistas.

The heaters for the camera are a similar resistive heating element and are powered by the main batteries. They are controlled by the Arduino Pro on its own separate power supply. Due to this the heater switching is handled by a relay rather than mosfets to ensure power isolation between the two circuits.
Figure 5: Function Block (Code Logic) Diagram for Camera System

Figure 6: Camera System Schematic
The chassis design, shown in Figure 7, allows for a modular approach to system integration. The four mounting sides each contain holes threaded for machine screws to allow for easy installation of mounting brackets. The upper and lower rings provide protection as well as a containment system for the flight string tube, ensuring that the payload cannot fall off.
Figure 7: Chassis Design.
Figure 8: Satellite CAD model

Figure 9: Satellite Exploded View – Only major components are shown for clarity.
4.0 Management

The team consists of four members, shown in Table 1, with help from outside sources such as web forums and our lab assistant, Tom Leps. There is no team leader. All major decisions are determined by the group. Each team member is responsible for his own portion of the project. The outer shell will be built by the whole group.

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Role</th>
<th>Primary Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adam Baker</td>
<td>Radiation Monitoring</td>
<td>Design and build radiation monitoring system.</td>
</tr>
<tr>
<td>Bill Fellman</td>
<td>Skeleton and Video</td>
<td>Design and build skeleton and video systems.</td>
</tr>
<tr>
<td>Nick Laitsch</td>
<td>System Monitor</td>
<td>Design and build system monitor, main heaters.</td>
</tr>
<tr>
<td>Charles Hakes</td>
<td>Advisor</td>
<td>Help troubleshoot, keep on track, give advice.</td>
</tr>
</tbody>
</table>

Table 1: Team Structure.

The team’s Gantt chart is shown in Figure 10.

Figure 10: Gantt chart for time management.
5.0 Budget

The team’s budget is shown in Table 2. Some parts were sourced from the electronics lab on campus at no cost to the team.

<table>
<thead>
<tr>
<th>Component</th>
<th>Total Mass (g)</th>
<th>Total Cost ($USD)</th>
<th>Manufacturer</th>
<th>Part #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arduino Mega 2560</td>
<td>40</td>
<td>$36.80</td>
<td>Unknown (eBay special)</td>
<td>N/A</td>
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<td>Arduino Pro</td>
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<td>$19.95</td>
<td>Sparkfun</td>
<td>DEV-09219</td>
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<td>Arduino Uno</td>
<td>25</td>
<td>$20.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accelerometer</td>
<td>2</td>
<td>$27.95</td>
<td>Sparkfun</td>
<td>ADXL345</td>
</tr>
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<td>Compass</td>
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<td>$35.31</td>
<td>Robot Electronics</td>
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<tr>
<td>GPS</td>
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<td>$49.95</td>
<td>Trimble</td>
<td>Lassen IQ</td>
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<td>GPS Shield</td>
<td>24</td>
<td>$19.50</td>
<td>Adafruit</td>
<td>GPS Shield</td>
</tr>
<tr>
<td>GPS Antenna</td>
<td>50</td>
<td>$12.95</td>
<td>Onshine</td>
<td>ANT-555</td>
</tr>
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<td>Temperature (x5)</td>
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<td>$10.00</td>
<td>Analog Electronics</td>
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<td>$85.00</td>
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<tr>
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<td>Sparkfun</td>
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</tr>
<tr>
<td>Camera (x5)</td>
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<td>$107.10</td>
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<td>12 V battery</td>
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<tr>
<td>3.7 V battery</td>
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<td>$0.00</td>
<td></td>
<td></td>
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<tr>
<td>Al Chassis</td>
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<td>$0.00</td>
<td>Self</td>
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<tr>
<td>Foam</td>
<td>500</td>
<td>$8</td>
<td>Great Stuff</td>
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<tr>
<td>Wires, heaters, misc.</td>
<td>200</td>
<td>$50.00</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Shipping</strong></td>
<td></td>
<td><strong>$41.09</strong></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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<td><strong>$567.40</strong></td>
<td></td>
<td></td>
</tr>
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</table>

Table 2: Mass and cost budget.

Since the mass limit was 1,500g a couple of components were dropped. As the counting system could be connected to the Arduino Mega, the Uno and its data logging shield were dropped. The antenna of the GPS was shortened by 4m. With only one Geiger tube functional the counting circuit was reduced in size as well. Preflight mass came in at 1,611g.

6.0 Test Plan and Results

Each system of the team’s BalloonSat is designed to operate independently. As such the bulk of testing will also be done independently. As each component is completed it will be vacuum tested then freezer tested. The parts will be combined for whip testing and a four hour bench test.

The physics and engineering department at Fort Lewis has an eight-inch diameter clear glass bell jar for vacuum testing. Each component will be placed in the bell jar and dropped to -30 inHg of pressure. The components will be operated at this pressure for fifteen minutes and observed for continued functionality.
Freezer testing will be in Fort Lewis College’s biology department deep freezer at -100 °C. If the freezer is unavailable, a cooler full of dry ice will be substituted. Each system will be turned on and tested in the freezer for thirty minutes.

Whip testing will be completed once all components are operational and secured to the skeleton. The complete satellite will be strung onto a rope and dropped twenty feet then stopped abruptly before hitting the ground.

Each component will also be bench tested individually and as a combined unit. Each part and code segment will be tested for functionality as it is added.

**Radiation Monitoring**
At the beginning 5 Geiger Tubes were tested for functionality. Each tube was hooked up to a high voltage power supply. The signal coming out of the tube was monitored with an oscilloscope. The results from this test showed only two out of the five tubes were functional, reading a background noise of about 41 bpm. For the vacuum test LED lights were attached to the four outputs of the counting circuit visual confirmation of Geiger readings. A Geiger tube was placed under vacuum for 15 minutes. The system continued to count at about 35 bpm. When a radioactive sample was held near the bell jar the LED light blinked more rapidly, confirming that the system was working properly. The Geiger system was not freezer tested.

Once it was determined that only one Geiger tube was working a much simpler counting circuit was built. Since no multiplexers were needed it just consists of one Hex Schmitt Trigger and one Binary Counter. It only took up 6 Digital pins, four inputs and two outputs. After playing around with it, it seemed that sometimes it would count 6+ counts for a single count. This was because the signal was not as clean as it could have been so a third capacitor was placed and solved the problem. After everything was fixed the Geiger tube was getting a background radiation of about 41 bpm (Beats per Minute).

**System Monitor**
Each component of the system monitor was tested as it was added. Testing began with the Arduino Mega, GPS logger shield and five temperature sensors. The system was combined and placed in a refrigerator to log data for as long as the used 9v battery attached would run. Figure 11 shows the results.
Figure 11: Data log of temperature as a function of time inside a refrigerator. Sometime after this sensor 1 began reading several degrees higher than the rest of the sensors.

Figure 11 shows the slight variation in temperature readings between sensors. This was consistent in all future testing.

Additional testing was performed with the accelerometer, compass and GPS as they were added. Each recorded reliably during regular bench testing and in a vacuum. For freezer testing heaters switched by the Arduino via MOSFETs were added. Dry ice testing logs were lost but showed successful regulation of temperature within a few degrees of the target 10 °C. The GPS could not be tested in the cooler because the antenna could not pick up a signal. Serial communications with the GPS did continue to function though.

A power supply issue prevented the Mega from functioning during the whip test. However, once the power supply issue was corrected the Mega and all attached sensors functioned fine.

**Skeleton**
As the skeleton was an aluminum t-slot frame it was determined that vacuum and freezer testing were not necessary. The whip test had no effect on the aluminum frame. The mounting tabs and stand-offs shown in Figure 12 all held well during the test.
Figure 12: Chassis with several components mounted using nylon stand-offs and metal screws.

The foam body was more problematic. Several attempts at fabrication led to total failure with the foam not curing properly within the PVC pipe shell. The team tried using a Styrofoam cooler but, as shown in Figure 13, it failed structural testing.

Figure 13: Foam cooler shell failure. The foam was too thin and broke.
A later attempt using aluminum window screen and Great Stuff foam proved to be more effective. The results are shown in Figure 14. An outer layer of foam was added to this to cylinder for extra padding and insulation. The wire was trimmed to fit, the shell was cut in half just below the horizontal center then the interior was hollowed out for the equipment. This combination did very well in whip testing.

Figure 14: Foam body mold with aluminum window screen. The screen added weight but doubled as structural reinforcement and a Faraday cage. Its main purpose was to allow even access to air so the foam could cure properly.

**Video**

The video system was the simplest of the three systems on the flight. The camera modules selected were fully self-contained units capable of accepting up to 8 gigabyte sd micro data cards and logging the video independently. The only duty of the Arduino Pro controlling them was to power them on and depress the record buttons.

The cameras had ample recording time allotments and were capable of each recording the entire flight on their own, up to 4 hours, with nothing but a press of the record button pre-flight. However, if power were lost prior to the writing of a long video file the entire clip would be lost. In order to provide a robust capture system video was recorded in standardized 5 minute blocks. This ensured the capture of some video during the flight should a portion of the system fail.

In addition to breaking the video up into blocks, the cameras were cycled off and then on in between video blocks to ensure that they always all began a new video clip in the proper state. The switching of the cameras was handled with npn transistors with pull-down resistors on the in-leg to ensure clean signaling. See Figure 6. The switches were prototyped and the code was restructured and massaged many times over with the whole system bench tested many times throughout. All functioned as expected and increased in reliability with subsequent prototypes to the final build.

The cameras were real-world crash tested extensively on a toy rc helicopter. The system was also vacuum tested and both put in a standard kitchen freezer and on dry ice for a period.
There were also to be altitude triggers for camera events, including the timing of the up-cameras to capture the balloon rupture and the switching to different logging routines during descent. The altitude triggers were to come via a simple “high-pin” communication from the main Arduino Mega. Unfortunately a last-minute soldering mishap the night before the launch disabled our GPS unit and precluded this method.

To overcome this hurdle it was decided that a simple absolute timer would be the best solution. Not wanting to add weight to the payload and the compounding inability to quickly reprogram it just moments prior to launch to set the proper trigger times, it was decided that was not feasible. The ultimate solution was to create a simple minute counter that would append to the EEprom of the Arduino Pro. The initial timer would start by adding this value (0 initially) and all subsequent restarts, for whatever reason, would begin with the freshly reset incremental millisecond timer and add the stored lapsed value from the EEprom. This successfully maintained an absolute minute timer to stage events that also has the advantage of starting itself at power-up and using no external memory.

### 7.0 Expected Results

**Radiation Monitoring**  
The team hoped to gather the data from five Geiger tubes and compare it against historical data as well as establishing a new baseline for future missions. The team expected to see an increase in radiation levels as the payload rises in elevation since the atmosphere blocks most of the radiation from reaching the earth’s surface. With a Geiger tube pointed down towards earth the team hoped to gather data on any local increase in radiation levels possibly related to the recent nuclear disaster in Japan. Data gathering was tested using an SD Logger shield on an Arduino Uno. The comma delineated files were retrieved from an onboard SDHC card.

**System Monitoring**  
The team hoped the data from system monitoring will help future teams design more efficient satellites. Component temperatures, current draw, rotation and acceleration data can be used to inform future designers of what they are up against. The data was stored in a comma delineated file on an SDHC card via a GPSLogger shield and an Arduino Mega. Retrieval of data requires recovery of, and reading, the SDHC card.

**Video Capture**  
The team hoped to get some great pictures! It was also hoped that the effective 60 fps capture-rate of the upward-oriented cameras would capture images of the balloon as it ruptured at elevation.

### 8.0 Launch and Recovery

All of the team will be present for the launch and recovery of the BalloonSat. After recovery the data cards will be retrieved and the files will be copied over to laptops on site. Retrieving and reading the data files from the SDHC cards has been successful in the lab.
The launch site was at the now-dry Ramah Reservoir NE of Colorado Springs. The launch morning of July 30 was clear and cool with very calm skies and only wisps of clouds. Temperatures started cool in the mid 60’s but were expected to reach well into the 80’s. The flight-path prediction software forecast a fairly short flight with the landing point predicted to be within a 12 mile range approximately to the west-north-west. The actual landing occurred very close to the predicted being approximately 8.5 miles from the launch and very near the WNW heading.

The launch and recovery went very well. An image of the BalloonSat on the flight string is shown in Figure 15. The payload was swinging a lot immediately after release but appeared to calm down after a short time. The recovery required a short hike through a pasture after negotiating access with the land owner. The payloads for the balloon were strung out perfectly across the ground with no visible damage to the team’s satellite. After retrieval one of the camera’s SDHC cars was found partially ejected but still confined to the camera body. All other systems still appeared to be functioning.

Figure 15: Team SkyHawk's BallonSat on the flight string just prior to launch.
9.0 Results, Analysis, and Conclusion

Radiation Monitoring
Before the flight only two Geiger tubes were working. With the payload overweight the team only mounted one Geiger tube. This tube was hooked to the bottom since it seemed that the more interesting data would be the radiation coming from the earth. Also the Geiger tube was connected to the Arduino Mega to further reduce weight.

There were no results from the Geiger system after the launch. This failure was not because of hardware but more directly from a non-connected power line to the counting system. This failure could have been foreseen if there was a simple LED light on the counting circuit board to distinguish if the system was getting power or not. This problem arose after diagnosing a problem with the Arduino Mega the night before the launch.

System Monitoring
The systems monitor component was only partially successful. Due to last-minute issues with electrical systems the GPS ceased to function. Later it was found that the voltage monitor was not stepped down low enough. It was dropped to 4V but the reference value of the Mega had been changed to 3.3 V to accommodate the temperature sensors. This was not noticed until the last minute when it was too late to make changes. During the last two days before launch the Geiger system monitoring was moved over to the Mega as well. In that time either a code or electrical problem resulted in no readings being gathered from the tubes. One of the temperature sensors also began reading consistently high a few days before launch.

Still, data from other sensors proved to be interesting. Data was recorded roughly once per second for 116.29 minutes. Logging began at the beginning of the flight, stopped and began again for three minutes once the unit was on the ground (determined by temperature readings in the 40–50° range for the last log). Compass readings show the satellite was spinning quickly for most of the flight. This was expected behavior based on the experience of previous flight teams. A graph of the whole log is shown in Figure 16.

![Figure 16: Compass heading during the flight. The heading changes indicate the satellite was spinning constantly.](image-url)
Figure 17 shows the first instants of the flight where the satellite was more stable. Note that the heading range is 0-360°, meaning going from 359° to 1° is only a 2° rotation. This is can be confusing when viewing these graphs.

Figure 17: Heading during the first 400 seconds of flight. The satellite did not spin much initially. Once the spin began it did not cease.

It is unclear what was causing the spin though video from the flight suggests the square payload below the satellite was an influence. It was rotating more quickly than this team’s satellite, possibly due to the shape catching more wind.

Temperature data indicates the main heaters were very successful at maintaining temperatures though a smaller 25 Ω heater on the SD card was less so. Figure 18 shows the data logs of the temperatures during the flight.

The temperature sensor Battery 1 is the sensor which was not functioning properly prior to launch. It was located on the same LiIon battery pack as the other battery sensors. It was simply reading high. The interesting thing this reveals is that while the heater on that part of the battery did not switch on until it dropped below the 10°C line, that part of the battery still
stayed warm from the other heaters until everything exploded later on in the graph. This indicates that the team could likely have gotten by with fewer heaters on the battery. The temperature increase on the SD card between 3000 and 4500 seconds indicates it was generating enough heat during this period that it did not need a heater.

When the sensor Battery 1 is removed and Battery 2-4 are averaged and plotted with the Mega SD Card sensor the behavior of the system becomes clearer. Figure 19 clearly shows the battery heaters stabilizing at about 8°C for a long period then becoming erratic 4800 seconds into the flight. The erratic behavior beginning around 4800 seconds makes sense when it is compared with the accelerometer data shown in Figure 20, Figure 21 and Figure 22.

![Figure 19: Average battery temperature and SD Card temperature as a function of time. The SD card was self-heating up until wind speeds through the satellite became too great during free fall.](image)

![Figure 20: Acceleration data from the x-axis. Note the acceleration spike around 4200 seconds. This is likely when the balloon popped.](image)
Figure 21: Acceleration data from the y-axis. Note the acceleration spike around 4200 seconds. This is likely when the balloon popped.

Figure 22: Acceleration data from the z-axis. Note the drop to zero g's around 4200 seconds. This would indicate the time period when the satellite was in free fall.

The acceleration data indicates a trend towards stabilization before an abrupt spike in activity at approximately 4200 seconds. This indicates a key event during the flight, such as the balloon bursting. When compared with the sudden variation in temperature behavior this appears to be the time when the balloon burst and the satellite began to fall. The increase in wind speed may explain the difficulty the heaters had in maintaining the target temperature. The open center of the chassis did not provide adequate protection and insulation from wind.

Where the data abruptly ends there is another spike in acceleration for all three axes. The time frame appears to correspond with the end of the flight. It is unclear why the system stopped monitoring upon landing.

The video system functioned exactly as expected with one glaring exception. While all components functioned correctly and in proper sequence, the video loop counter was erroneously left in bench-test mode and not increased to accommodate for the duration of the
flight. All of the cameras performed well taking video and storing it in 5 minute blocks until the counter hit 10 and then the program ended. As near as can be discerned, because of this the team likely missed capturing the rupture of the balloon by only a scant few minutes. Doh!

Figure 23: Image of balloon from below near apex of flight. Note dipole antenna of the beacon above and intensity of reflected sunlight.
Figure 24: Views near apex of flight. You can clearly see the effective limits of the atmosphere. The curvature of the earth is also apparent though it would be more so if the camera were oriented properly. This is planned for next launch along with adding a second side camera to double the width of the shot.
Figure 25: Views from downward cameras were primarily obscured by the proximity of the payload below but were very interesting nonetheless.
Figure 26: At the times that the payload below us was spinning much faster than our payload relatively speaking this cool bending effect is observed. While it could appear relativistic, the speeds are not great enough to observe length contraction. We believe that this phenomenon is actually the result of the miniscule delay (~33ms through exposure) in the progressive scan writing of the pixel data to the file. Note that earth below is not similarly skewed.

The chassis worked very well. It allowed easy mounting of components and survived the flight without a scratch. It should provide a flexible, light-weight platform for future modularized payloads.

10.0 Ready for Flight

For the system monitor only a few things need to be done for the system to be flight ready again. The surface mount for the GPS needs to be replaced and tested first and foremost. Additional resistors need to be put in series with the existing ones on the voltage monitor to drop the measured value below 3.3V. Additional current monitoring positions should be added with code updates to reflect such. The faulty temperature sensor should also be replaced. Everything else works great.

A lower voltage battery will be used so that regulating down is not as much of an issue. It will also be lighter as our first battery was more than necessary. We will also pare down mass anywhere else possible including removal of material from both aluminum and the steel end-ring structures.
For the camera systems we would like to maintain our position nearest the balloon on the lift-line to capture the balloon rupture, but hopefully we can be afforded much more room below us so that our downward view is less obscured. We will move one of the downward-oriented cameras to the side of the satellite to catch more curvature of the earth. The existing side-camera will be re-oriented so that the long side is horizontal. The two side cameras will then be placed close enough to one another so that their pictures can be stitched into a combined panorama to effectively double the width of our field-of-view. We will reinstate the GPS trigger to allow for altitude coordinated queuing yet we will retain the absolute timer for redundancy. And of course, the counter will be set to something much larger than 10!

11.0 Conclusions and Lessons Learned

Wind causes the satellite to rotate throughout the flight. As witnessed in the video it also changes directions of rotation frequently rather than rotating continually.

High wind speeds appear to wreak havoc on the heater system of the satellite.

The 30 fps rate of the cameras is sufficient to capture good images despite the rotation of the satellite.

While aluminum window screen does work well as a mold for the expanding polyethylene foam, it is overkill as a faraday cage and adds too much weight.

The team also learned that Russian cold-war military surplus Geiger tubes are very unreliable.

A simple LED light should be used for a systems check for all circuit boards that are receiving power this can help extensively for simple diagnostic issues.

12.0 Message to Next Year

Our message to next year is to get started as soon as possible! Also:

- Test early and often.
- Reduce wind intrusion as much as possible.
- Use the smallest batteries possible.
- KISS – Keep It Simple Stupid. Using fewer parts/systems makes life easier and allows for more thorough testing.