**Purpose**

The purpose of BalloonSat flight nine consisted of many different things. The first purpose was to test the transmitters after they flaked out in BalloonSat flight eight. A second purpose for flight nine was to launch a high definition video camera which was recorded and transmitted via ATV. Another purpose was to fly a MAE 311 strain gage project. The final purpose of BalloonSat flight nine was to complete an outreach project with Mr. Jason Satterfield’s 7th grade geography class at Sparkman Middle School. The Sparkman Middle School outreach experiments were designed and fabricated by the students with the aid of UAH Space Hardware members. The goal of completing this outreach project was to give younger students an opportunity to have a hands-on experience with real near-space experiments in order to try and help spark an interest in science, technology, and engineering. The students were very enthusiastic with their involvement the project and were very impressed by the launch itself.

**Experiments**

1) Trackers and the Ground Station
2) High Definition Video Camera
   a. ATV
   b. Attitude Estimation
3) 311 Strain Gage Project
4) Sparkman Middle School Outreach
   a. Bubble Wrap & Marshmallow
   b. Aluminum Foil & Water Bottle
   c. Bread
   d. Ground Camera

**Experiment Description and Results**

1) **Trackers and the Ground Station**

Three trackers were flown on BalloonSat flight nine. The two Space Hardware Club trackers, KJ4NKE-11 and KJ4NKE-12, were flown on the standard amateur HAM radio frequency of 144.390 MHz. A backup tracker, KG4WSV-14, was flown on an alternate frequency of 144.340 MHz.

The trackers acted great at the beginning of the day of the flight. However, after launching, the trackers started to have some trouble. The two Space Hardware Club trackers failed to reliably transmit KJ4NKE-11 transmitted good data packets every several minutes. KJ4NKE-12 also transmitted data packets, but without GPS position data. Because of these issues with the transmitters during the flight, the chase and ground station teams switched to the alternate frequency and tracked KG4WSV-14 for the remainder of the flight.

At recovery, KJ4NKE-11 was found without an antenna and batteries removed. KJ4NKE-12 was found with its antenna and some of the batteries removed. The batteries are suspected to have been shaken out of place during the removal from a tree during recovery. The problem with transmission is suspected to have been related to close proximity to the ATV 5 Watt transmitter. The Space Hardware Club trackers were only approximately 10 feet from the ATV transmitter. However, the backup tracker, KG4WSV-14, was much farther away. Close proximity to the ATV transmitter may be linked to the GPS malfunctions and transmission failures. In order to solve this mystery a flight without the ATV transmitter will be conducted.
2) High Definition Video Camera

a. ATV

BallonSat flight nine was the second flight of the ATV payload, which can be seen in Figure 1. However, this time there were modifications made from the previous flight based on the results in hope to get better. The modifications included the removal of more insulation to alleviate an issue of overheating and adding a rigid support system for the antenna in order to ensure good transmission quality and relieve the stress on the antenna cable. With these modifications made the payload operated well above expectations. The video feed was clear and was even received in Bowling Green, Kentucky. Unfortunately, all of the insulation and some of the electronics were damaged during the recovery of the balloon from a tree.

The two goals of the ground station included: one, using the 70 centimeter antenna to receive live video downlink from the ATV payload and two, using the 2 meter antenna to receive APRS data packets and track the balloon during flight. Unfortunately, due to suspected problems with the pre-amp and the 70 centimeter antenna, no ATV signal was received by the ground station even though it was received by team members on a hand held receiver. Also due to problems with the transmitters, the call sign we were tracking had to be switched and no data was received from the first half of the flight by the ground station. Once the control program was adjusted for the change in call sign, tracking commenced and data was received until the balloon went over the horizon. All received data was uploaded to http://space.uah.edu where it was also visible in Google Earth, which can be seen in Figure 2.
b. Attitude Estimation Experiment (Gyro, Compass and Data Logger)

In order to avoid a writing error that occurred during the last launch, the data logger’s reset function was enabled. The data logger (4Dsystems uDrive-uSD-G1) is rebooted if the reset pin is pulled down for more than three milliseconds (See Figure 3). In the data acquisition system, the microcontroller (Atmel ATmega168) pulls the reset pin low when data write command is not successfully completed. The improved system successfully recorded data for approximately 11500 seconds (3.3 hours).

![Figure 3: Data Logger](image)

Figure 4 shows heading [degrees] and heading rate [degrees/sec]. The heading values come from an electric compass unit and the heading rate values are average of output of two rate gyros. In general, both plots look like they represent the BalloonSat’s motion. The plots indicate the balloon was launched at around 2000 [sec] and popped at approximately 9700 [sec]. However, there are four issues.

![Figure 4: Raw Data](image)
First, the heading does not exceed positive or negative 50 degrees (Figure 5). It does not make sense. The flight video shows the payload rotated more than 360 degrees. The data should show the rotations. The possible cause of error is disturbance of magnetic field due to ATV signal. The electric compass is a sensitive magnetometer, and can be easily disturbed by artificial magnetic field. In order to determine why this happened, Space Hardware Club will test the compass with and without ATV or equivalent transmitter before the next launch.

Second, the heading rate suddenly began damping around 10300 [sec] while the heading plot indicates the payload kept tumbling after the heading rate plot had completely damped (Figure 5).

Third, the data itself must contain some errors. Figure 6 shows ΔHeading of both the compass and the gyro. ΔHeading is defined as:

\[
\Delta\text{Heading}_\text{Compass}_j = \text{Heading}_j - \text{Heading}_{j-1}
\]

\[
\Delta\text{Heading}_\text{Gyro}_j = \frac{\text{Heading}_j - \text{Heading}_{j-1}}{t_j - t_{j-1}}
\]

Where \( t \) is time [s]. Theoretically these two values should be equal. However, \( \Delta\text{Heading}_\text{Gyro} \) is approximately four times bigger than \( \Delta\text{Heading}_\text{Compass} \). These errors might be caused by error in calibration and sensor’s performance characteristics or there might be significant error in the datasheet. Space Hardware Club will inspect error causes and improve the hardware and software before the next launch.
Finally, significant drift of gyros’ output was detected (Figure 8). The drift is caused by acceleration and is an intrinsic error mode of any MEMS rate gyro. This can be mitigated with digital (software) filters such as Kalman filter, but the filters were not implemented for this launch because Space Hardware Club did not know how significant the drift would be. The data obtained from this flight pointed out the filters are definitely needed. Space Hardware Club will try to implement Kalman filter in Spring 2010.
3) MAE 311 Strain Gage Project

The goal of the strain gage project was to design and build a strain gage circuit that allowed the user to measure the tension in the parachute cord between the balloon and the rest of the balloon payload line throughout the entire flight. In order to complete this project a strain gage system was fabricated by the Space Hardware Club and the MAE 311 Project Group and added to balloon payload train. The strain gage measured and recorded the strain (in Volts) throughout the flight. This strain data was then used to convert from strain (in Volts) to force (in lbf) using the following equation. This equation was found during calibration of the strain gage circuit:

\[ F = \frac{(\text{strain in Volts} - 0.1639)}{0.0584} + 1.9696 \]

In order to conduct such an experiment a strain gage system needed to be fabricated. Figure 6 shows the schematic of the strain gage.

![Figure 8: Strain Gage and Temperature Sensor](image)

![Figure 9: Strain Gage Circuit](image)
Figure 10: Strain Gage Schematic

Strain Gage
Operational Amplifier
Data Logger

R1 = R2 = 560 Ohm, R3 = R6 = 120 Ohm, R4 = R5 = 1 Ohm, R7 = R8 = 150 KOhm, R9 = 10 KOhm
C1 = C2 = C3 = C4 = 0.1uF, C5 = C6 = 18pF

MAE 311 Project
Strain Gage Circuit
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Rev 1.0
11/19/2009
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Temperature readings from the temperature sensor attached next to the strain gauge, as shown in Figure 11, were found using the following method

\[ T_A = \frac{V_{out} - V_{0^\circ C}}{T_c} \]

**Force**

Figure 11: Temperature of Strain Gage

Figure 12: Measured Force vs. Time
The forces plotted in Figure 12 were found using the following equation:

\[ \text{Force} = \frac{\text{strain} - 0.1639}{0.0584} + 1.9696 \]

**Conclusion**

The temperature spiked to around 50°C around 20 minutes after the microprocessor began recording data. The strain gage measurements spiked at this time as well. In fact, the force measurement went outside of the resolution of the microprocessor. However, all of this occurred before the balloon was released from the ground. Therefore, the team believes that the change in force is simply due to the temperature change from the heaters that caused the resistance of the strain gage to change. This also indicates the temperature change caused the voltage readings related to force to go about the maximum resolution of the strain gage before the balloon was launched. Therefore, the target data unfortunately ended up being outside of the resolution of the microprocessor. If the strain gage that was used would have come with some kind of temperature compensation then useful data may have been recorded. The next step is to further test the strain gage system in a static condition under known temperature loads. This will allow the team to find out how to change the amplification of the strain signal and try to find a temperature compensation correction.
4) Sparkman Middle School Outreach

a. Bubble wrap & Marshmallow

The bubble wrap & marshmallow experiment was a project that was thought up, designed, and fabricated by 7th grade students from Sparkman Middle School with the help of UAHuntsville Space Hardware members.

The bubble wrap & marshmallow both expanded throughout the flight as the atmospheric pressure dropped. Figure 13 and figure 14 show the initial and final states of the bubble wrap and marshmallow, respectively.

b. Aluminum Foil & Water Bottle

The aluminum foil & water bottle experiment was also a project that was thought up, designed, and fabricated by the same 7th grade class at Sparkman Middle School. The middle school students wanted to see what happened to the temperature of a piece of aluminum foil and a water bottle during the entire flight.

The outcome to this experiment was sort of disappointing. The wire of the electronics board going from the microprocessor (which records the data) to the temperature sensors on the aluminum foil and the water bottle was ripped off. Therefore, there was unfortunately not data collected on the temperature of the aluminum foil & water bottle.

c. Bread

The bread experiment was also an experiment that was thought up, designed, and fabricated by the 7th grade students from Sparkman Middle School. The students wanted to see if a piece of bread would mold. The result of this experiment was also unfortunate. When the payload was recovered the piece of bread was not there. Therefore, no data was recovered about the bread.

d. Ground Camera

The down camera was an experiment that was thought up by the UAHuntsville Space Hardware members. The 7th grade students helped fabricate the packaging for the down camera. The down camera worked well and provided the students an opportunity to compare the pictures to a topography map – especially since the class was a geography class. Figure 15 was one of the many pictures taken from the down camera experiment.