Abstract

Project Norris is designed to determine whether lithium-polymer batteries can perform at least as well as the alkaline batteries for the duration of the balloon flight. Lithium-polymer batteries would reduce the mass needed to power the satellite as well as saving money due to their ability to recharge. Reducing the base mass of the payload could allow future projects more experimental variety. Project Norris is essentially a performance comparison test between two types of batteries in BalloonSat applications.

1. Introduction

The Colorado Space Grant Program’s BalloonSat Project is a unique opportunity to collect valuable data directly from the stratosphere. The chosen experiment should collect some type of data that cannot easily be replicated by scientists on ground level. The data itself needs to be collected in a manner that properly isolates the target variable as there are numerous variables associated with a balloon ascent into the stratosphere: temperature, pressure, altitude, humidity, radiation, etc. Finding a suitable experiment is half the battle; the other half of the battle is staying under the mass limitation of 850 grams.

The BalloonSat is required to run a minimum of four 9V alkaline batteries; three to power the heater and one to power the arduino. Depending upon the power demands of the experiment it may be necessary to run more than four batteries. Each of these batteries weighs an average of 45 grams. The four required batteries account for roughly 20% of the total payload mass and each additional battery will utilize another 5% of the total payload mass. This places power limitations on the experiment and restricts the variety of experiments that may be performed. Reducing the base mass of an experiment with mass limitations is an important engineering consideration as it will increase the mass allowed for the experiment.

Team Voltanators aims to address this battery mass burden by demonstrating that lithium-polymer batteries are at least as reliable as alkaline batteries in powering the electrical components of a payload. Due to their lighter mass, they can effectively reduce the mass percentage of battery to payload, leaving more available mass to house a larger variety of experiments. The lithium-polymer batteries that will be used in this experiment have an average mass of 35 grams. Four of these batteries accounts for roughly 15% of the total payload mass. Replacing alkaline batteries with lithium-polymer batteries will increase the available experimental mass by at least 40 grams.

Another important engineering consideration is always money. It is arguable that money may be the most important engineering consideration. Having a rechargeable power source saves money over time as fewer batteries would be needed for testing and launch per team.

Lithium-polymer batteries have the ability to recharge and they take up a smaller percentage of the payload mass than the alkaline batteries that are currently in use. Team Voltanators will determine whether the lithium-polymer batteries are capable of effectively replacing the alkaline batteries in future BalloonSat experiments. The experiment will be successful if the lithium-polymer batteries are at least as effective as the alkaline batteries in powering the payload for the duration of the flight.

2. Project Norris

The subject of batteries is overwhelmingly complicating and rather unnecessary for a battery performance comparison test. Project Norris is designed to determine whether lithium-polymer batteries can match the performance of the alkaline batteries for the duration of the flight. Project Norris will accomplish this task by running a side-by-side comparison of lithium-polymer and alkaline batteries by measuring the voltage change with respect to time under a constant load.

A successful mission requires that the lithium-polymer provide enough current to the load for the duration of the flight while maintaining an ambient box temperature...
roughly equivalent to the ambient box temperature provided by the alkaline batteries. Prior to flight, numerous battery drain tests will occur on the ground. Voltage drain curves with respect to time will be gathered as well as temperature readings for both the primary (alkaline) and secondary (lithium-polymer) batteries individually in order to compare the average ambient temperature of the box provided by the primary and secondary batteries during their discharge; if the ambient temperature provided by the lithium-polymer batteries is roughly equivalent to that provided by the alkaline batteries then the first condition of mission success is met.

The second condition involves the batteries voltage drain with time, the alkaline and lithium-polymer batteries will be discharged individually under a constant load within the box until cutoff voltage is reached. If the arduino collects voltage readings then there must be current flowing through the circuit; if there is current flowing through the circuit and the box is heating then there must be current through the resistors. Therefore, we can directly compare the lithium-polymer and alkaline drain times using voltage readings as confirmation of functionality. In order for this condition to be met the lithium-polymer batteries must maintain a voltage above the cutoff voltage for at least as long as the alkaline batteries both under the same constant load.

A successful flight is the third condition and it will provide the final confirmation that lithium-polymer batteries are a reasonable power alternative for BalloonSat experiments. This condition demands that the lithium-polymer batteries match the performance of the alkaline batteries during the actual flight itself. The data collected by the arduino must adhere to both conditions 1 and 2 during flight in order for condition 3 to be valid as these are the performance conditions.

The BalloonSat specifies the use of three 9V alkaline batteries whose function is to provide thermal control of the box for the duration of the flight; if the lithium-polymer batteries provide the same level of functionality as the alkaline batteries then the lithium-polymer batteries would be a reasonable power alternative in BalloonSat experiments.

3. Design

3.1. External Design Features

Project Norris was constructed from foam core. The foam core was cut into a cross shape and folded into a cube. At each fold location a triangular incision was made with an Exacto knife to allow the sides to fold with ease. Hot glue was used to seal the sides of the payload together. Aluminum tape was then applied around the exterior edges of the box that had required the hot glue. The dimensions of the box are 18cmx21cmx9cm (LxWxH). Project Norris has bumpers surrounding the exterior edge of the bottom face of the box. The bumpers were constructed from Nomaco insulation and applied with hot glue. This is done in order to cushion the landing of the payload itself.

A small circular incision was made on the top and bottom face of the box in order to allow the housing of the flight string tube. The incision was made in the center of the box.

The inside of the box was lined with Nomaco Insulation on all sides. The switch is located on a side face of the box. It is routed through the insulation and should conserve heat. The hole was also cut into the foam core for external access to the switch.

Figure 2. Original conception

Figure 2 shows the 3D proto-type developed prior to the actual building of the satellite. The actual satellite is half this height and no internal chamber was designed to house the components. This was an expected occurrence and an updated 3D design is currently under construction.

3.2. Arduino Design Features

The payload houses five sensors: One analog pressure sensor; one analog accelerometer; and three digital temperature sensors. The pressure sensor and accelerometer were necessary components to satisfy general BalloonSat requirements common to every CCA flight team. However, the three digital temperature sensors are unique to our design. There is a two-heater system in our design; they act as both a heat source for the payload and as a load to discharge the alkaline and the lithium polymer batteries. In order to show that the heaters are being powered independently of each other, we felt it was important to use two temperature sensors to measure the independent temperatures of the two heaters. One heater is powered by 3 9V alkaline batteries in
parallel, while the other heater is powered by 3 9V lithium polymer batteries in parallel. In our battery bench testing, the heater powered by the lithium polymer batteries routinely maintained a higher temperature than the heater powered by the alkaline batteries. We would not have known this information without the use of two independent temperature sensors in our design.

There are three ceramic heater resistors (4Ω each) connected in series and soldered to a perf board. These resistors are subsequently connected in parallel to two 1kΩ resistors in series, which are soldered onto the Arduino protoshield. The 1kΩ resistors in series function as a voltage divider. This design feature is necessary because the maximum operating voltage of an Arduino Uno for any of its data I/O pins is 5V; a 9V battery connected directly to any of the I/O pins would damage the microcontroller. Hence, a voltage divider setup was necessary in our design to split the voltage of the 9V batteries between the two 1kΩ resistors in half, to a value of less than 5V. The Arduino reads the voltage of each trio of batteries from the analog pin as half of the actual voltage, then the value is multiplied by 2 to determine the actual voltage of the batteries at any given time. Our design has two of these heater/voltage divider setups: One for the 3 9V alkaline batteries connected in parallel, and one for the 3 9V lithium polymer batteries connected in parallel.

The three digital temperature sensors are connected to an OneWire bus, with one shared 4.7 kΩ pull-up resistor. The beauty of this design is it only takes one digital input pin to get independent readings from three different temperature sensors. The first digital temperature sensor (Thermo0) reads the temperature at the back of the perf board connected to the first heater powered by the alkaline batteries; the second digital temperature sensor (Thermo1) reads the temperature at the back of the perf board connected to the second heater powered by the lithium polymer batteries; the third digital temperature sensor (Thermo2) reads the ambient temperature of the external environment of the box. The bit resolution of the digital temperature sensors was modified in the Arduino code to 12, which yields a temperature accurate within 0.0625ºC, but slows down the transaction rate between the Arduino and the sensor to ~750ms. For our experiment, temperature accuracy is more important than the response rate of the temperature sensors, which is why we chose to increase the bit resolution from its default.

The Arduino microcontroller is programmed to take readings from the sensors once every 2 seconds, and it writes to the microSD card once every 10 seconds. Through battery bench testing, we decided these read/write rates were optimal for our experiment. The number of data points had to be enough to accurately demonstrate the voltage behavior of the draining batteries, but not too high in order to not overwhelm the microcontroller with excessive current drain.

4. Structural Testing

The ascent of the satellite into the stratosphere is rough. Structural tests must be conducted to ensure the protection of the data and functionality of the electrical components. The structural tests to be performed prior to launch are as follows:

1. The Whip Test- Project Norris must be able to withstand the G-forces that will occur during the balloon blast while attached to the flight string. We will attach a thin rope of two meters through Project Norris using a knot underneath to prevent slipping. Then we will swing Project Norris around in an open field to simulate the balloon blast.
2. The Drop Test- Project Norris must be able to withstand heavy impacts with the ground while maintaining the functionality of all components contained within the payload. In order to simulate poor parachute deployment effects on the landing of Project Norris we will drop the payload from the second story of our campus building onto concrete and make necessary adjustments until the drop is completed successfully.
3. The Stair Test- Project Norris must be able to withstand the harsh jerky ascent into the atmosphere. The payload will be thrown down two flights of stairs.
4. The Cold Test- Project Norris must be able to withstand the temperature range of the atmosphere as it ascends into the stratosphere. In addition, Project Norris must maintain thermal control of the electrical components as it makes the ascent. We will place Project Norris in a Styrofoam container with dry ice for two and a half hours. This test will verify functionality of the payload under low atmospheric like temperatures.

5. Method

Project Norris requires the collection of temperature data and voltage data; the arduino will collect this data and store it to an SD-card. Temperature sensors will determine the first condition and voltage sensors will determine the second condition. The successful storage of data during the flight that meets the first two conditions will determine the third condition. The conditions are summarized below for reference.

1. The secondary batteries attain and maintain at least as much heat as the primary batteries.
2. The secondary batteries remain above the cutoff voltage at least as long as the alkaline batteries.
3. During flight, the secondary batteries meet conditions 1 and 2.

The tests will be conducted in a fully assembled payload. The batteries will be tested individually as well as together within the payload. Three 9V batteries are wired in parallel and connected to three 4-ohm resistors in series. The resistors produce the heat. A temperature sensor connected to the arduino records the temperature produced by the heater at any given time and records it to the SD-card.

In order for the resistors to produce heat, there must be a current flowing through them. A voltage sensor is used to collect voltage data at any given time through the resistors and this data is stored on the SD-card. The arduino input for the voltage sensor only allows 5V. In order to reduce the voltage measurement two 1-kohm resistors in series were connected in parallel to the heat resistors. The voltage sensor takes measurements between the two 1-kohm resistors and the arduino converts it to the respective voltage through the heat-resistors using Ohm’s Law (V=IR). The two groups of resistors are connected in parallel to the same power source so they must have the same current flowing through each of them. Figure 1 illustrates this circuit.

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The launch will occur with both the primary and secondary batteries performing the discharge test. An LED light will communicate that the arduino is saving data to the SD-card for a few minutes after the switch is turned on just before the flight.

6. Data

The following graphs were the result of the first trial:

Graph 1. Voltage vs. Time

Graph 1 illustrates the voltage discharge with respect to time of the lithium-polymer batteries (red) and the alkaline batteries (blue). The secondary batteries maintain a larger voltage for a longer period of time. The red line is stopped due to concerns at the time of the true cutoff voltage associated with that specific battery.

Graph 2. Voltage behavior
Graph 2 represents the voltage fluctuation behavior with respect to time. The lithium-polymer batteries are steadier in their discharge voltage than the alkaline batteries. Current data suggests that the lithium-polymer batteries are able to perform the functions of the alkaline batteries in a BalloonSat setting.

6. Conclusion

Project Norris will provide data regarding the effectiveness of the Hitech Rechargeable Lithium-Polymer 9V batteries as a low mass replacement to the traditional Energizer Alkaline 9V batteries used to power the payload during flight. The arduino is programmed to read the voltage drain as a function of time which will verify that the lithium polymers provided power to the heater for the duration of the flight. The data collected will determine whether the lithium-polymer batteries are an effective and reliable replacement for the alkaline batteries.

The current data suggests that the lithium-polymer batteries are able to perform the tasks at least as well as the alkaline batteries. More data needs to be collected before a conclusion can be made.

The secondary batteries will reduce the base mass of the BalloonSat allowing for more variety in experimentation due to the additional mass allowance. In addition to this, the secondary batteries are rechargeable whereas the primary batteries are not. This feature allows multiple use of the same battery. Over time, the lithium-polymer batteries will prove to be more cost effective than the alkaline batteries.