



High Altitude Ballooning for Space and Atmospheric Observation

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I. Project Summary

The purpose of our project was to conduct a series of high altitude balloon experiments on student-designed launch platforms. Many design goals were considered, including, but not limited to: horizontal control for helium weather balloons, tethered camera platforms (controlled and passive), rocket and glider payloads, self-stabilizing platforms, high-definition video platforms, and miscellaneous data collection. Over the course of the project, the High Altitude Ballooning Group completed two successful high altitude launches and several workshops on payload design and microcontroller programming. We have also conducted tests on tethered camera payloads, including field tests in Alaska for a related JPL study on imaging methane seeping from under frozen lakes.

II. Introduction

a. Technical Motivation and Opportunities

In the summer of 2010, the Caltech Ballooning Group participated in a competition titled “Hackerspaces in Space” which introduced us to the field of high altitude aerial photography with weather balloons. Over the course of three months, we launched two simple payloads, but were only able to retrieve one. This was due to the fact that our funding was limited – our onboard cameras were used and broken and our tracking system consisted of a prepaid cell phone with GPS. The airframe for the surviving payload was cut from scrap Styrofoam. Regardless, the payload we retrieved took amazing pictures and piqued our interest in the field.

With funding from the Keck Institute for Space Studies, our project group hoped to investigate the mechanics of high altitude flight with multi-balloon launches and controlled landings for payloads. We also wanted to test cost-effective tethered camera platforms and their advantages and limitations compared to other forms of aerial imaging. To increase efficiency and the rate of recovery, we also wanted to design rugged, reusable payload airframes with modular ports that would allow for many different experiments and instruments. This included a more advanced flight computer that would monitor GPS data and sensor inputs.

Finally, our group wanted to increase awareness of amateur high altitude projects in the Caltech community by holding informal workshops for Caltech students.

b. Scope of the Project

With the generous funding from the Keck Institute, we were able to design a number of balloon payloads, but due to time constraints we had to focus our attention on a handful of projects. Our main focus dealt with aerial imaging with a stabilized platform and relaying the images to ground stations. At the same time, we produced reusable, modular payload frames that would allow us to develop experiments more quickly and

efficiently. We also wanted to measure the internal pressure in the balloon and its changes during flight. Understanding changes in internal balloon pressure could help us optimize multi-balloon launches which would allow us to increase the maximum altitude and flight duration of our payloads. Finally, we wanted to design a payload that would relay video of an untethered flight back to a ground station.

III. Project Launches

a. High Altitude Launches and Field Experiments

First Launch – August 14th, 2011

The first launch was a prototype to test the new equipment as well as the Spot GPS transmitter used to track the balloon during its flight. The secondary purpose of the launch was to introduce new group members to launch and retrieval procedures.

Payload

Since this was a prototype to test the new equipment and the airframe did not need to be reused, we used inexpensive insulated cooler bags. The three main components of the payload were a camera, a Spot GPS messenger, and a microcontroller programmed to record the balloon's GPS position.

Camera – We chose to use a Canon PowerShot SD550 as

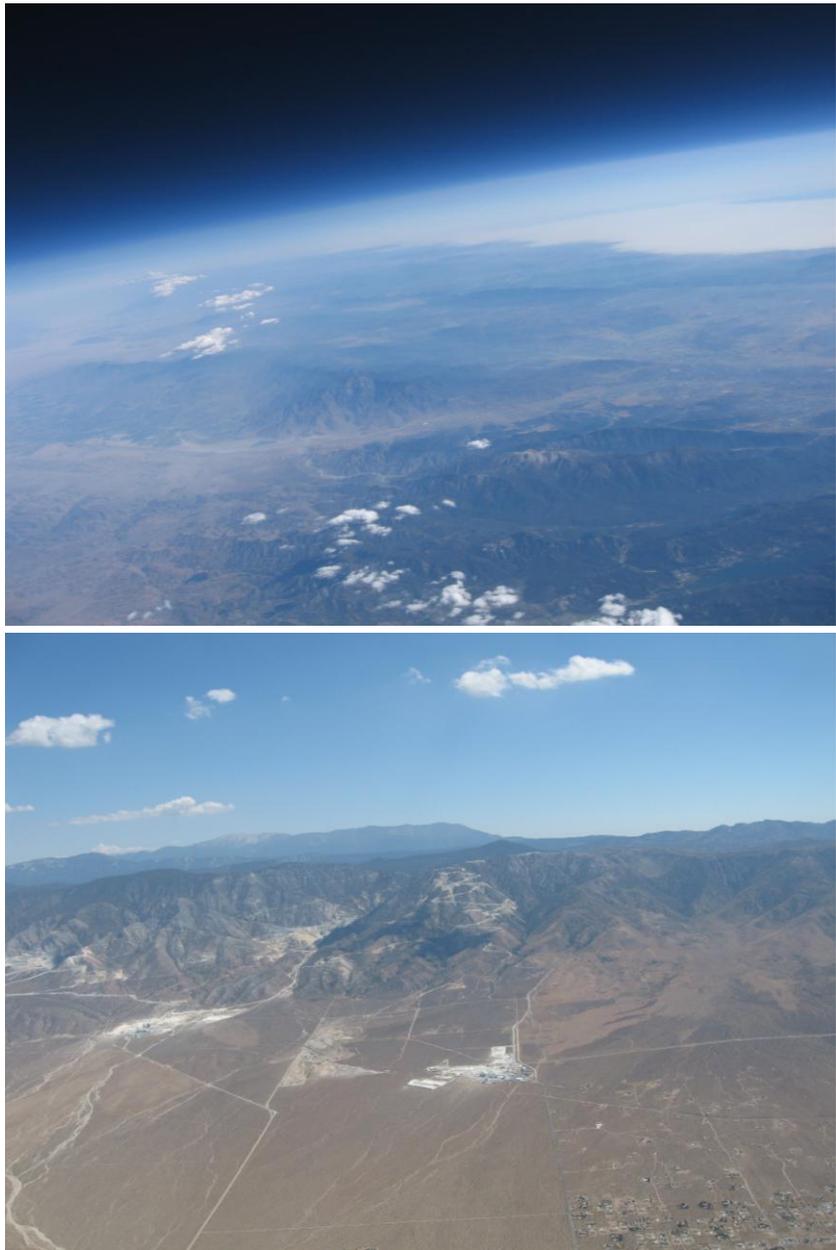


Fig. 1 Pictures taken by balloon at its peak altitude and during ascent

the onboard camera. Using the Canon Hacker Development Kit (CHDK), we reprogrammed the camera to act as an intervalometer to take pictures at set intervals. This camera was used in a previous launch and provided surprisingly detailed pictures even with its low resolution.

Tracking system – The Spot GPS messenger broadcasts its current GPS coordinates through a satellite link every ten minutes. The GPS data points are then recorded onto the Spot website. This allowed us to track the balloon nearly in real time. Unfortunately, the device only worked up to around 22,000 feet so it would only record the initial launch and the final descent. Still, it continued to broadcast its position after landing, making retrieval of the payload much simpler than with the faulty tracking system in our previous launches.



Fig. 2 The balloon's flight path over Lucerne Valley

Microcontroller – We used an Arduino Uno microcontroller with a GPS logging shield to record precise GPS coordinates throughout the launch. The microcontroller was programmed in C++ to record GPS position data every second and to store it in an onboard SD memory card. This gave us a very detailed plot of the path the balloon traveled. This was necessary since the Spot messenger could only transmit coordinates every ten minutes and only when it had a stable fix at low altitude.

Our first payload took two attempts to launch. The single-use airframe proved too unstable and heavy for the smaller 200 gram weather balloon we used, so we had to scrap the airframe and use a lighter, more compact container with less insulation. The launch, however, was a success, and the payload was recovered after four hours.

Second Launch – September 25th, 2011

Our second launch was the first real use of our reusable payload airframe. With a sturdy Styrofoam base, it contained five experiment ports (four to the sides, one pointing up), each five inches square. An abrasion jacket made from rip-stop nylon covered the whole airframe to reduce wind and landing damage as well as strain on the package from the parachute tethers. The number of connections to the parachute

was increased from one to four. This stabilized the payload and provided redundancy in case one of the tethers snapped. This launch also contained a more comprehensive scientific payload, as well as an enhanced flight computer and a high definition video camera.

Payload

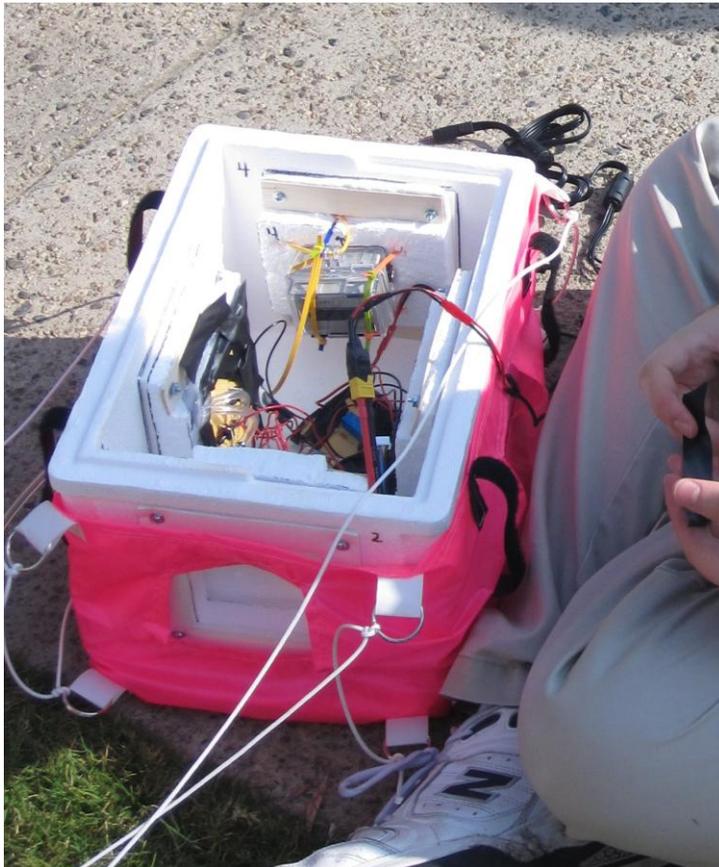


Fig. 3 Modular payload airframe with abrasion jacket

weather balloon. Plastic tubing was run from the payload to a brass pipe inserted into the neck of the balloon to make this measurement. Unfortunately, the sensitivity of the gauge pressure sensors was too small to show a significant difference between balloon and atmospheric pressure. After the balloon burst, the added weight from the tubing also destabilized the payload's descent causing damage to two of the five airframe mounting ports. Two temperature sensors were used to measure inside and outside temperatures, but the inside temperature sensor failed due to an electrical short. Nevertheless, the outside temperature and atmospheric pressure sensors worked correctly and were used to estimate the peak altitude at around 92,500 feet.

HD Video – The second main objective of this launch was to record high definition video of the entire flight. We used a GoPro HD Hero camera set to 1080p. A GoPro Battery BacPac was added to increase the operation time of the camera well past the duration of the flight.

Flight computer – The Arduino microcontroller with GPS data-logging shield was reused for this launch, but the code was updated to include altitude and to log data from the sensor array. The microcontroller also handled time-dependent in-flight events, such as a siren/LED unit to help locate the payload after landing. It performed well during the flight, but the recorded raw data was in an unmanageable format and required a time-consuming conversion until it could be analyzed.

Sensor array – One of the main goals of this launch was to record temperature and absolute pressure inside of the payload. Gauge pressure sensors were used to measure the difference in pressure between the inside of the airframe to the inside of the

A secondary objective of this launch was to observe the balloon's expansion and burst as well as to monitor the condition of the pressure sensor tubing. The Canon PowerShot used in the August launch was mounted to the upward-facing experiment port and took pictures every five to thirty seconds. Not only did it capture the expansion and burst, but it also recorded the gradual change of the atmosphere's color from blue to black.

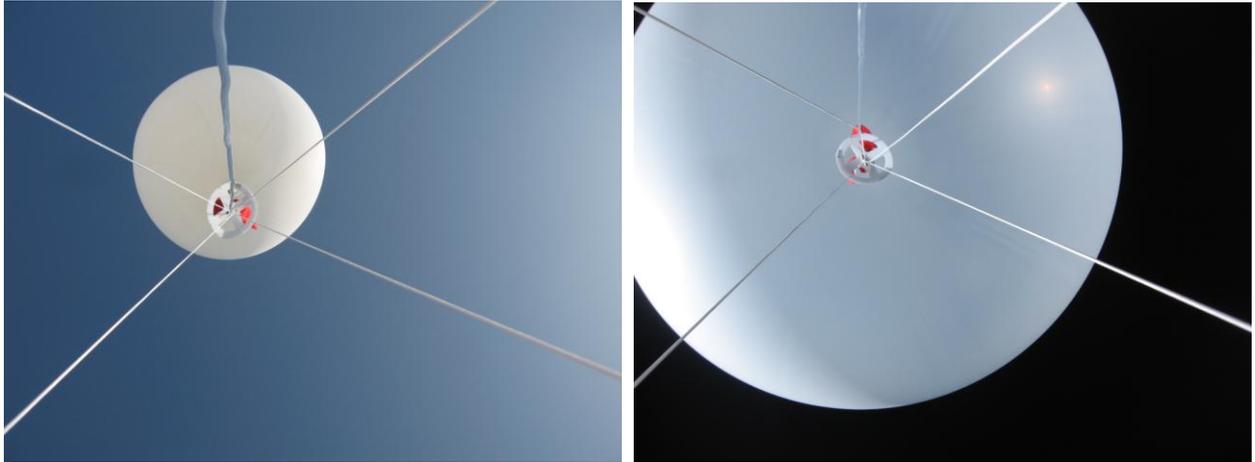


Fig. 4 Images from upper camera (left: early ascent right: peak altitude)

Field Experiments (and Canceled Third Launch)

The third launch contained an improved and repaired sensor array as well as a 1 Watt 2.4 GHz transmitter that would relay a live video feed from the GoPro camera. The port mounts were also rebuilt to be more durable than the last launch. The modular aspect of the reusable airframe proved to be extremely useful since we were able to rearrange various payload components in a more efficient placement. We conducted several successful ground tests with the transmitter, but unfortunately the launch had to be canceled due to high wind conditions.



Fig. 5 Stabilization tests with a tethered weather balloon

In addition to the payload ground tests, we also performed tests on the tethered aerial photography platforms that were to be used in Alaska. Information on those experiments can be found in the attached JPL report: "Identification of Methane Seeps

under Arctic Lakes”.

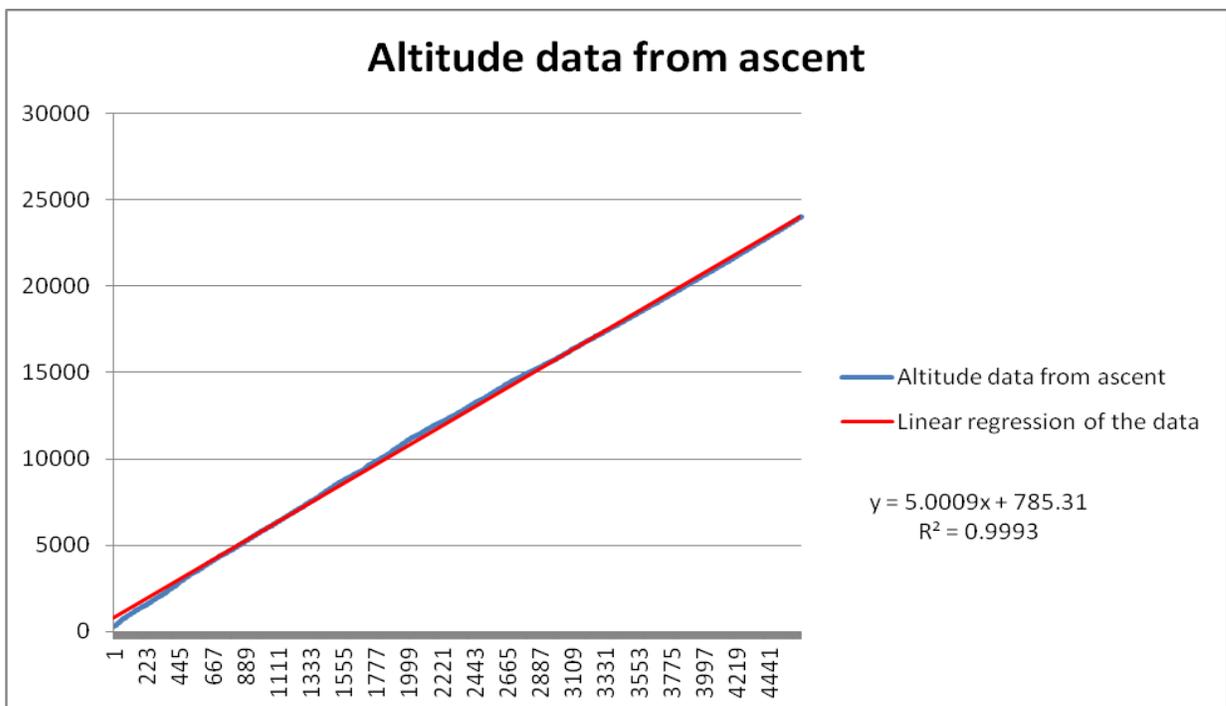
b. Design and Programming Workshops

One of our goals of this project was to increase awareness in the Caltech community of balloon experiments and to teach students how to design their own. We held two informal workshops in addition to our design meetings. They focused on two important aspects of balloon payload design: different payload subsystems and microcontroller programming. Each participant was given an Arduino Uno microcontroller kit and the chance to design their own experiments. We taught students how to code the microcontrollers in C++ and gave examples of various control circuits. Overall, it was a success and helped students understand the complexities of payload design.

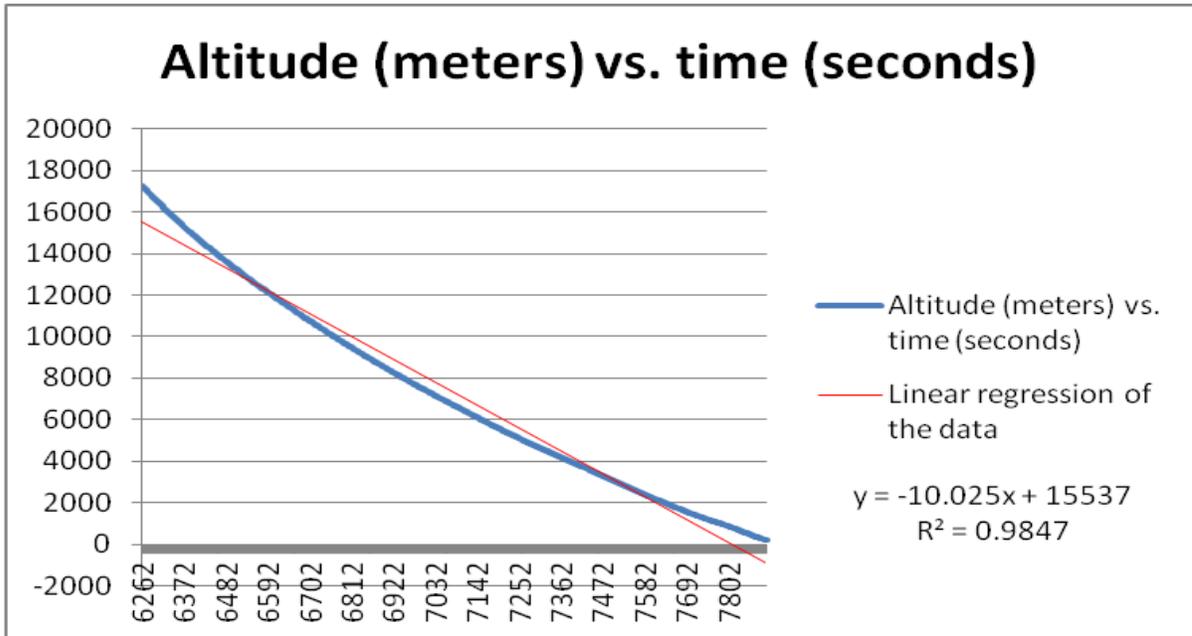
IV. Outcome of the Project

a. Results

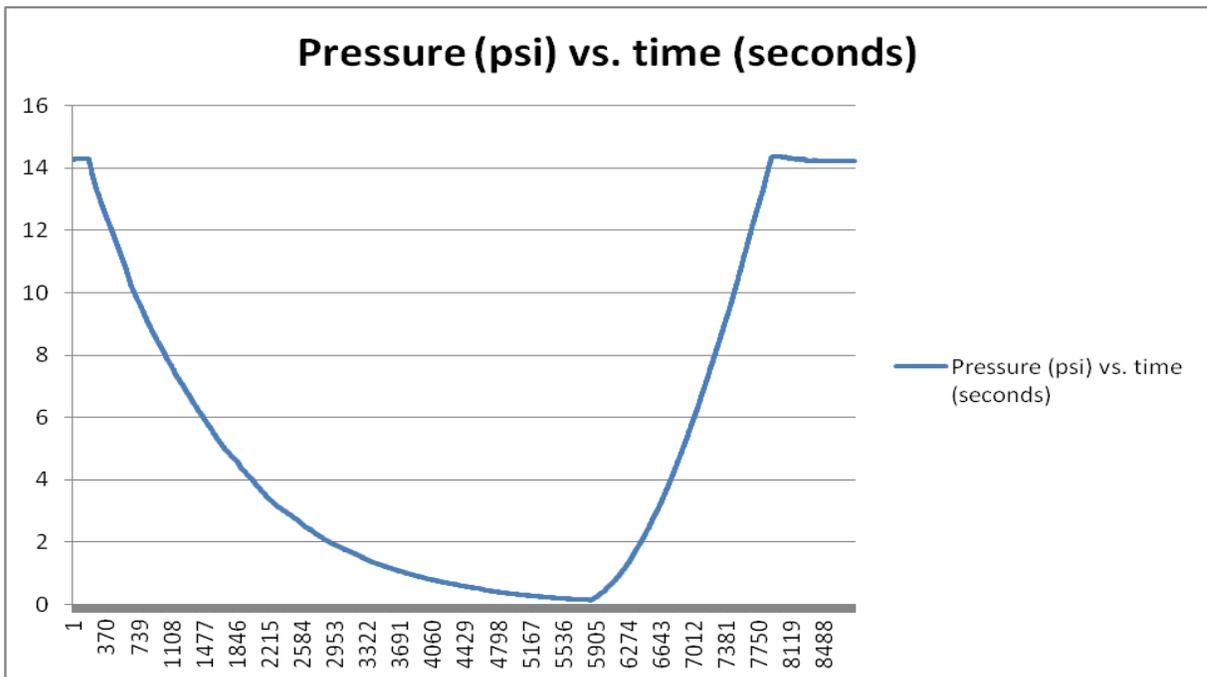
All of the photography platforms worked as intended as well as the data telemetry. The second launch payload provided key data in analyzing the flight profile of the balloon. From the altitude data, we found that the ascent rate was surprisingly regular even though the change in pressure was not. With a linear regression line, we found the ascent rate to be approximately 5 m/s.



Similarly, the descent rate could be calculated from the second half of the altitude data.



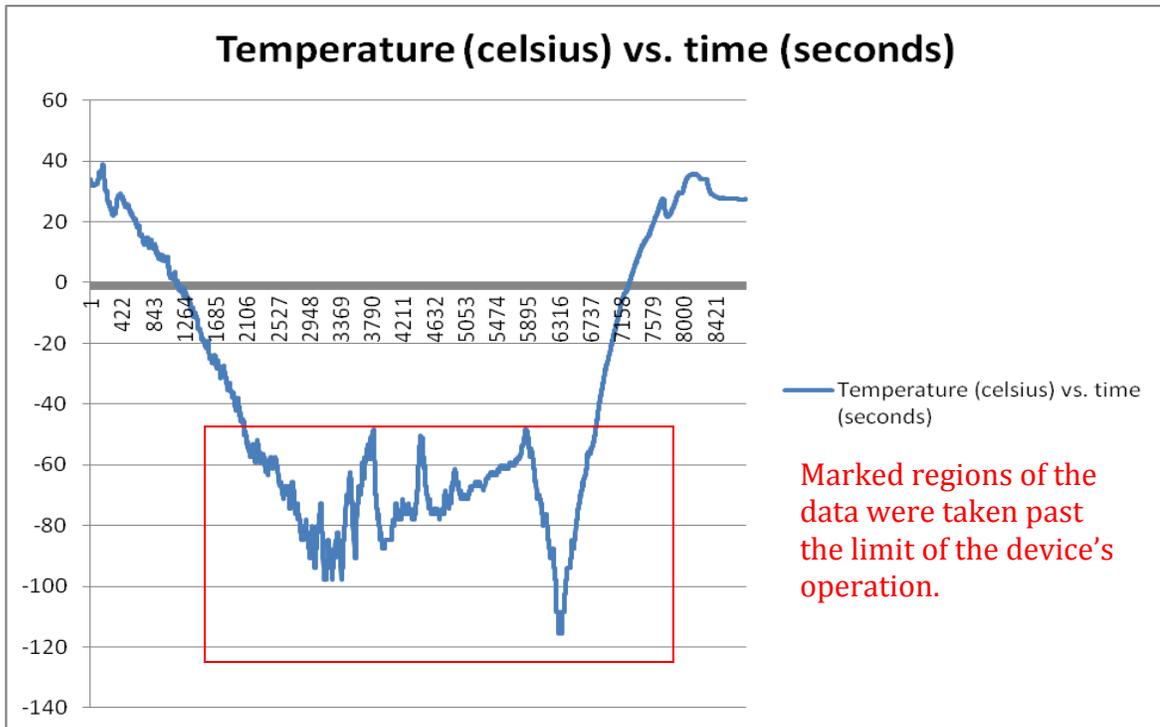
The regression for the descent rate gives 10 meters/second, but with deceleration due to the increasing density of the atmosphere the accuracy of the calculation decreases.



There was also a limit on the GPS altitude data recorded by the flight computer. The GPS failed above 24,000 meters and only would only reactivate once the payload dropped below 17,250 meters. This is due to the altitude restriction set by the US government on most GPS devices. In future launches we will use a GPS capable of accurate readings up to 85 km, but for this launch the maximum altitude had to be

extrapolated though the absolute pressure data.

The peak altitude corresponds to the minimum pressure during the launch. From the data, this occurs approximately 5642 seconds after the initial launch. With an ascent rate of 5 meters/second, this would give a peak altitude of about 92,500 feet.



Finally, we also took temperature measurements from outside the payload. The calibration overcompensates slightly near the limit of its operation (-40 degrees Celsius), and since the temperature sensors were not shielded from sunlight there are occasional spikes in the data. Although the temperature readings are inaccurate at the higher altitudes, the oscillation can help us determine the period of rotation for the payload. This can be used to help develop self-stabilizing components in the future.

b. Roadmap for Technical Development

Before any additional launches, we can improve the performance of the individual components of the payload. Mounting booms to the experiment ports can help isolate more sensitive sensors or add separation between multiple GPS devices to prevent interference. We could also shield various sensors to increase the accuracy of the flight data (shielding temperature sensors from sunlight, for example). We have already started modifying the GPS telemetry systems to provide more reliable, real-time GPS data through the Automatic Packet and Reporting System (APRS). This would decrease the payload recovery time and provide necessary redundancies in retrieving GPS data.

Although the reusable payload offered versatility and efficiency in payload construction, a truly modular design in which frames can be stacked together would facilitate payload design, construction, and repair. With a dedicated core module housing the flight computer and telemetry systems, we could then add on various specialized modules depending on the situation. Swapping out experiments would be much easier since we would not have to rearrange the internal components of the core systems for every flight. We could even launch multiple payloads in the same day by replacing the surrounding modules after the payload is recovered.

c. Current and Future Projects

In the immediate future, our group will be modifying our current payloads to accommodate live telemetry through packet radio broadcasts. This will require more experimentation on range and power requirements. After these tests are completed, we plan on developing high altitude rocket platforms. We would have to design a remote launch system that could initiate a launch through a timer or altitude event, but it would require more in-flight failsafes before we could get FAA approval. Also, we will need to improve the stabilization of the launch platform to achieve maximum efficiency as well as for safety reasons.

We also wanted to investigate the feasibility of a payload that would deploy from high altitude and return to the launch coordinates through an on-board GPS. A returning payload would allow us to set up a more permanent ground station where we could monitor the flight telemetry.

V. Conclusions

With the funding from the Keck Institute for Space Studies, our group has been able to make incredible strides in our understanding of payload design. We learned how to manage power resources to payload components and how to cope with stabilization and weight limitations. We ran extensive tests on multiple types of mobile aerial photography rigs and worked with members of JPL to conduct design experiments. We have researched multiple telemetry systems for GPS and live video feeds and will continue to do so.

Overall, this project has expanded all of our horizons. We started with broken parts and Styrofoam scraps, but now we have the resources for a fully operational near space program. What we have learned from this project will lay the foundation for more advanced research.

VI. Acknowledgments

There are many people and organizations that have helped us over the course of our project. We would like to thank Michele Judd, Tom Prince, and the rest of the Keck Institute for Space Studies for their generous support of our program. We would also like to thank Fiona Harrison for mentoring our project, Julian Nott for his insight into the field, Caprece Anderson, Debby Miles, and Nina Borg for their help managing accounts and ordering supplies, and John Leichthy for introducing us to JPL and for his considerable help and knowledge.

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