



University of Maryland HASP 2012 Final Report

Stratopigeon III

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Introduction

The University of Maryland (UMD) HASP team is pleased to submit the final report for the 2012 University of Maryland payload, Stratopigeon III. The University of Maryland has participated in 4 years of HASP flights, including 2 years of Stratopigeon payload tests. This report details the final design and testing results of the Stratopigeon payload, a new approach to data storage and delivery for LDB and ULDB Antarctic high altitude balloon flights. The Stratopigeon payload has been supported and funded in testing and flight by the Maryland Space Grant Consortium, with oversight and support from the UMD Space Systems Lab.

Overview

As the technology and techniques of high altitude ballooning improves, the duration of LDB and ULDB Antarctic flights have lengthened. Flights in excess of 3 months are now possible, allowing scientists more access time to the desired environment than previously available. As payload technology has also advanced, many research payloads are collecting more data, as much as several terabytes over a few weeks.

Research payloads store collected data on board, with a slower ground station link to verify payload functionality and data validity. Normally, a satellite link, such as Iridium or TDRS, or a line of sight link is used. These links are capable of data rates in the tens to hundreds of kilobits per second, a low enough rate that the majority of scientific data remains on board the payload for the duration of the flight. Due to the payload size, weight, and weather conditions of the landing site, recovery of on-board data is a difficult, resource and time consuming task. Experienced personnel and multiple plane trips are required for payload retrieval based on landing location, delaying recovery for days, weeks, or, rarely, not at all.

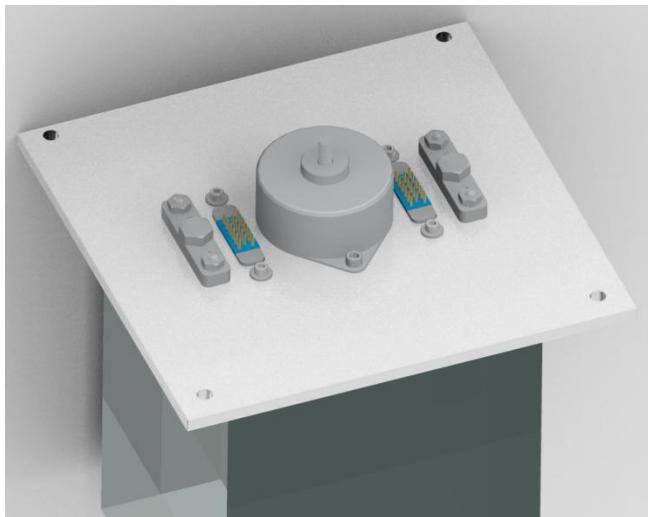
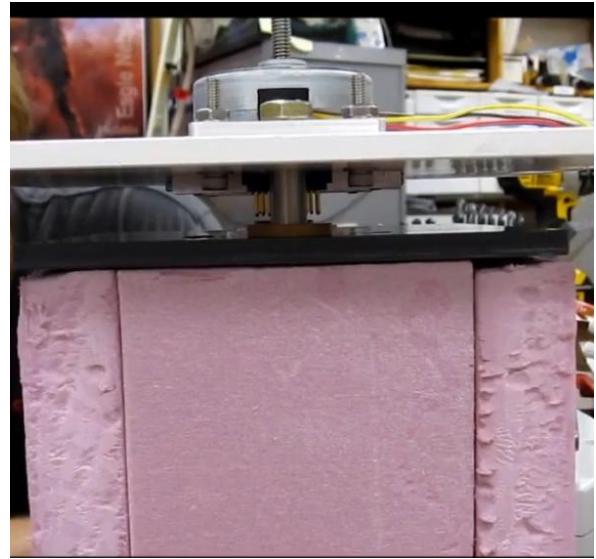
Stratopigeon III is the second generation prototype of a data storage and delivery capsule designed for supplemental data storage and mid-flight delivery of a high volume of scientific data. The small size of the capsule and ability to release the capsule at any point during flight allows easy retrieval of scientific data mid-flight. Not only does early retrieval allow for correction of anomalies shown in the data during flight, but analysis of a more complete data set can be accomplished at multiple points along the flight timeline.

The 2012 Stratopigeon capsule was designed specifically to minimize integration difficulty with already established research payloads. The data capsule was built and tested on the 2012 HASP flight and refines the previous prototype flown in 2010.

Final Flight Systems

Mechanical Design

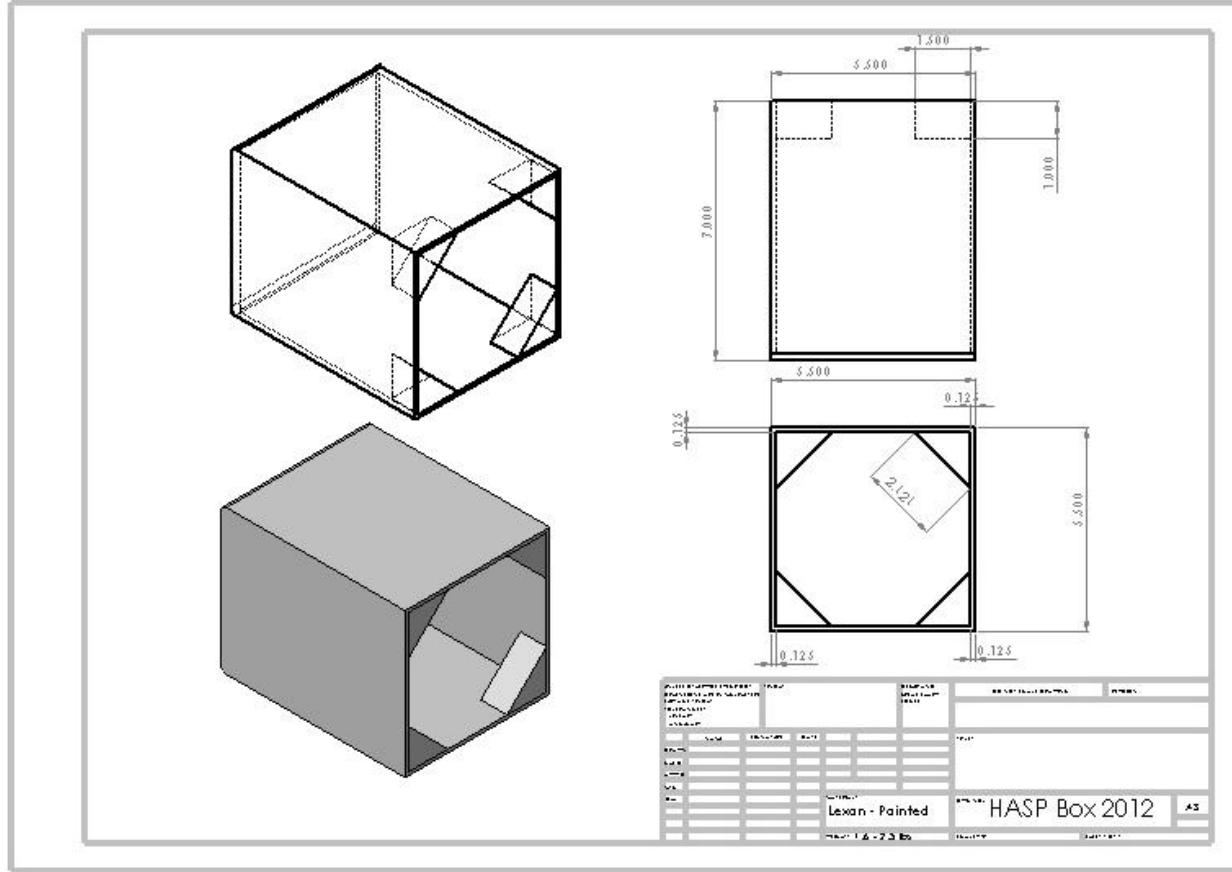
The mechanical system disconnects the payload and electrical connections from the gondola. Deployment of the payload is actuated by a linear stepper motor capable of outputting twenty-four pounds of force. The motor turns a nut inside its body and drives out a M6.35 threaded rod, approximately one and quarter inches in length, which is securely bolted to the top of the payload. This actuator, made by Anaheim Automation, is a simple and lightweight linear drive system that provides enough force, with safety margin, to detach the payload. Stainless steel guide pins, mounted to the HASP interface plate, guide the payload out on Teflon linear bearings, to prevent torquing during deployment and to guide the payload into place during assembly. Due to internal configuration of the payload, a single guide pin was used. The threaded rod, Teflon guides, and female Hypertronics connectors are attached on the payload and fall to earth with it. This detachment process actively separates the payload and interface plate which are driven apart an additional quarter inch after the connectors disconnect. The order of contact during assembly is as follows: first the guide pins, then the M6 screw, and finally the Hypertronics connectors, which allows the linear actuator to pull the payload up into position, making assembly possible by a single team member. For multiple assemblies and



disassemblies of the payload, this method saves time and effort in attaching the capsule to the gondola.

The payload enclosure was constructed from 0.118in thick polycarbonate material with base, width, and height dimensions of 5.5in, 5.5in, and 7in, respectively. This five-sided enclosure was constructed from seven pieces: three side pieces used to form the overall box shape, and four triangular corner pieces. During the manufacturing process, one 33.5in x 5.5in piece was bent into a "U" shape in order to create three of the five outer sides of the enclosure. The use of a continuous piece for three sides of the enclosure was selected in order to reduce the possibility of failure at the material connection points. This design choice contributed to increased structural stability upon impact. Two additional 5.5in x 5.5in polycarbonate pieces were used to complete the square enclosure. Flush with the open side of the enclosure, were four

triangular corner pieces that were constructed from the same polycarbonate material. These corner pieces resembled 45°-45°-90° triangles with sides of 1.5in and a hypotenuse of 2.121in;



each piece is 1.0in deep. Eight 4-40 screws, two in each corner piece, were used to secure the top plate to the payload enclosure. Each of the corner pieces also contained an attachment point for the parachute clasps. To reduce the effects of solar heating, the enclosure was painted with white Krylon Fusion for Plastic spray paint, which has an emissivity coefficient of 0.992.

Commercial Intel series solid state drives were mounted to two sides of the box. The communication system was mounted to the third side, and the battery mounted to the bottom of the box to locate the CG near the bottom on the payload. The top of the box was made of PVC material and housed the pin attachment to the motor and the parachute brackets. The top of the box was removed to access the internals of the payload. One antenna for the communication system protruded from the bottom of the box. The antenna had one bend point. Based on analysis of the landing of the 2010 prototype payload, the antenna had no protection from impact. No damage was found on crush pad used in the previous design iteration, therefore it was determined that the antenna would survive landing without additional impact protection. A parachute tube passed through the HASP plate and stored the 24" parachute. The estimated descent rate of the capsule was 17 ft/s. There were no significant issues encountered with the Stratopigeon III payload mechanical and structural design. The payload deployed as expected

during thermal chamber testing, bench testing, and during the 2012 HASP flight. The payload structure handled thermal and stress loads during thermal-vac testing and flight testing without deformation or cracking, as much as can be seen from the flight data.

Electrical Systems Final Design

Overview

The electronics systems in the data capsule were designed to be simple and compatible with already existing systems on scientific research payloads. Input from the CREAM Antarctic payload was used to determine requirements for the electronic interfaces to the data capsule.

The electronics system is composed of four printed circuit boards (PCBs).

The control board performs all operations, including repeater control and HASP communication. The communications PCB is internal to the dropped portion of the data capsule and contains a GPS unit and 900 Mhz radio. Two commercial SATA to USB PCBs are used to convert solid



state drive (SSD) output to a usable USB interface for the research payload. The control board is shown in the above picture.

The control PCB manages all intelligent payload functionality, including capsule detachment, temperature monitoring and heater management, internal USB signal routing, serial communications, and radio control. For motor control, an A3967 IC was used with an open source motor driver configuration in order to reduce development time. The motor driver can be socketed onto the PCB as a riser board, or populated on the control PCB itself. 250 mA of

current at HASP voltage was used to power the motor driver and drive the stepper motor for payload detachment.

The control IC is a Texas Instruments MSP430. This IC controls all on board functionality and contains all software needed to run the data capsule. The MSP430 was selected for its low power, high capability structure needed to run all aspects of the data capsule within the given low power requirements.

Thermal regulation is managed by the control PCB with four temperature sensors and three flexible Kapton heaters. Heater power is sourced directly from the HASP voltage and controlled with DPDT latching relays. Thermistors are co-located with each heater to ensure reliable temperature management.

On board power management at the control board is implemented with two PTN78000 DC/DC switching regulators. Each regulator outputs a maximum of 1.5A at 5V and 3.3V for various components in the payload subsystems.

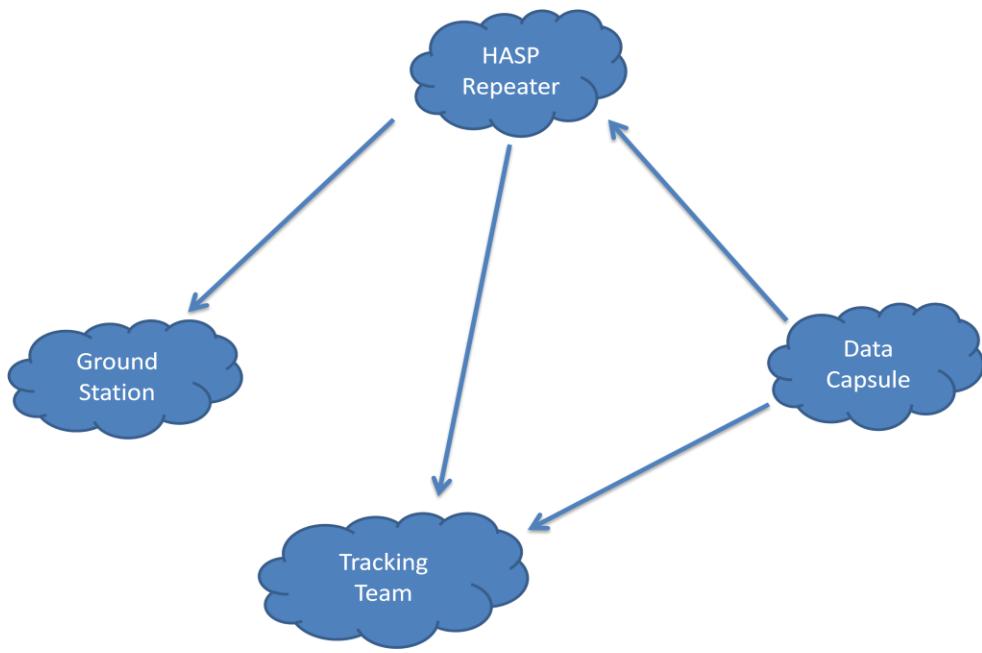
The control PCB also contains the interface to external science payloads through two micro-usb ports on the edge of the PCB. USB was selected as the capsule external interface in order to minimize software changes on the target research payload, given that each research payload already contains software to interface with attached hard drives. Therefore, a USB interface allows for easier and faster integration with the data capsule. Because SATA to USB conversion is a challenging electrical interface, commercial converters were used with each of the SSDs.

The USB to SATA interface and data storage capacity of the data capsule was tested with an external Linux computer prior to the HASP 2012 flight in the UMD test lab. However, due to a lack of a suitable simulated research payload, this interface and functionality was not tested on the actual 2012 flight.

Commercial SSDs provide a cheap and easily accessible data storage method for large amounts of data. However, as commercial devices, there are temperature limitations that preclude the use of commercial SSDs in extreme environments. In order to mitigate cold temperature requirements, a heater and thermistor were attached to each SSD, in addition to a metal heat spreader plate. Each drive was monitored by the payload and heated automatically as needed during the flight.

The communications PCB inside the data capsule consisted of power regulation, Digi Xtend 900 Mhz radio, and Lassen IQ GPS. The GPS was programmed externally to transmit one GPGGA string every 15 seconds to the radio. A PTN78000 was used to regulate power to the communications from the 9.6V LiPO4 battery. With 1 W of transmit power, the payload was designed to have a battery life of approximately 12 hours.

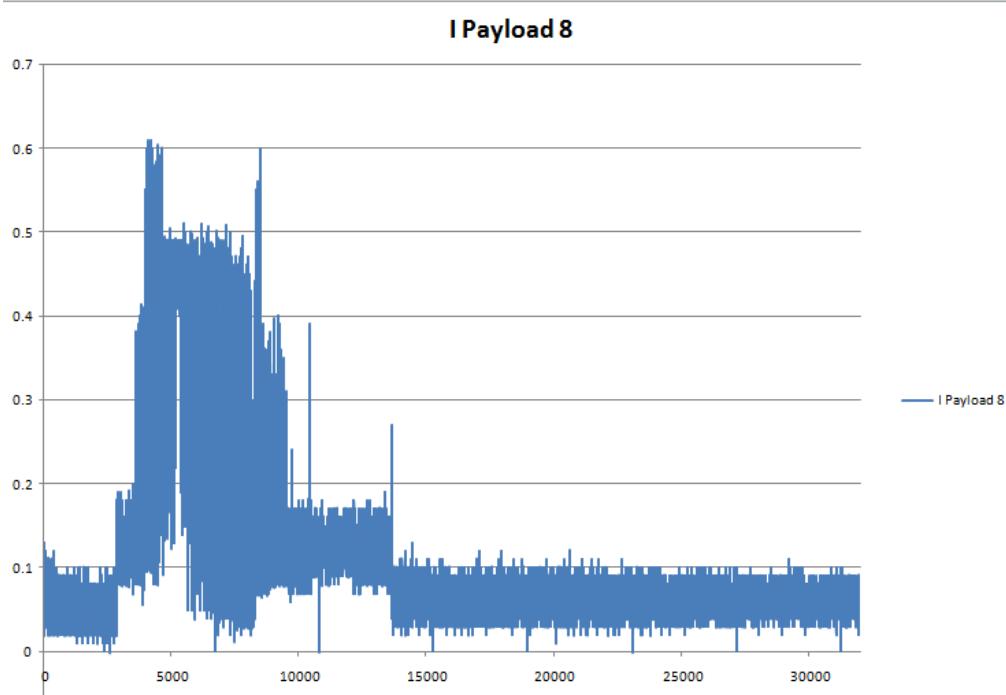
Line of sight communications to a base station with a low power payload at a distance and on the ground is challenging without any intermediary repeaters. In Antarctica, where there are no repeaters available for use, a different method of receiving signals at the base station is required. The control board of the Stratopigeon payload contains a repeating radio to solve this problem by using the balloon itself as a repeater.



The base station receives the tracking signal from the balloon, without needing to track the payload directly, eliminating the need for an external tracking team. If an external tracking team is used, radio signals are received from the balloon and the data capsule.

Electronics Flight Anomalies

The main issue in the electronics system relates to the current draw of the payload during the cold portion of the HASP flight. During UMD testing and HASP thermal vacuum testing, the current draw for the total payload remained below 0.58 A. During flight, as HASP passed through the coldest part of the ascent, the payload drew more current than expected, exceeding 0.6 A. A graph of the current is seen below.



Electronics Design Issues

In the original payload design, a Texas Instruments motor driver was used in a custom circuit to drive the detachment mechanism on the control PCB. In thermal chamber testing at UMD, this PCB successfully released the payload at various temperatures. However, during integration and further testing, grounding issues in the motor driver chip began to cause anomalies in other components on the PCB, rendering the design non-functional. A commercial motor driver was selected in order to mitigate further issues, add reliability, and reduce development time.

Software System

The Texas Instruments (TI) MSP430 was programmed using the TI Code Composer software in a version of C. Flight software created two strings sent over HASP serial for payload monitoring and housekeeping data. One string contains all housekeeping data. The second string responds to a command and confirms the number of the command received. Most structures, such as serial receive and transmit, are done through interrupt routines in the main program. A summary of the housekeeping string is as follows:

Transmit String Byte Number	Data
[0]-[3]	String beginning Identifiers
[4]	MSB Internal Ambient Temperature
[5]	LSB Internal Ambient Temperature
[6]	MSB External Ambient Temperature

[7]	LSB External Ambient Temperature
[8]	MSB Internal SSD 1 Temp
[9]	LSB Internal SSD 1 Temp
[10]	MSB Internal SSD 2 Temp
[11]	LSB Internal SSD 2 Temp
[12]	MSB Internal Battery Temp
[13]	LSB Internal Battery Temp
[14]	Heater 1 Status
[15]	Heater 2 Status
[16]	Heater 3 Status
[17]	Transmitter ON/OFF status
[18]	SSD ON/OFF status
[19]	Repeater ON/OFF status
[20]	Motor ON/OFF status

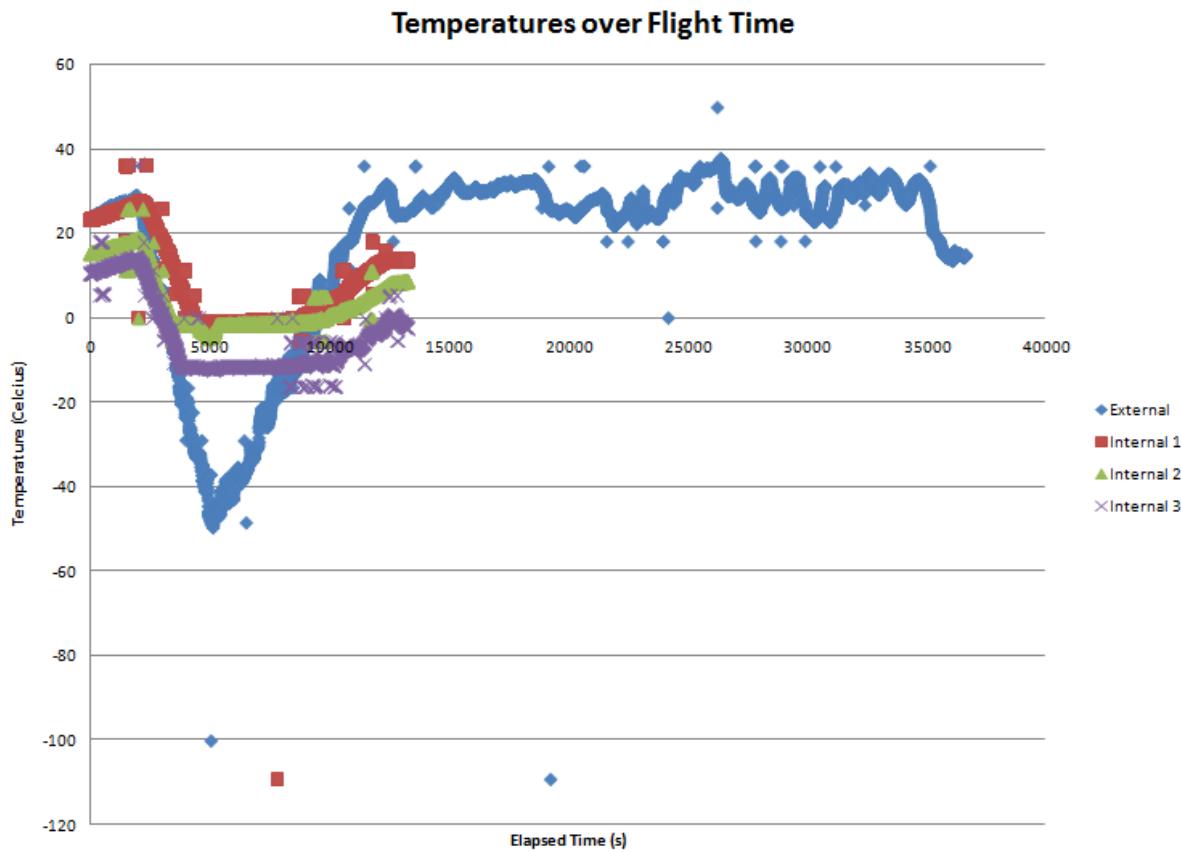
A well supported user interface and coding base was essential to low development time and software learning curve. A single control chip for the data capsule also allowed the software to be consolidated into one short program which was easier for multiple users to understand and debug. This method of software development showed a significant improvement in development time, ease of use, and ease of interfacing with other payloads over the design challenges faced in the 2010 Stratopigeon prototype. A discussion of software design is presented in the failure analysis section of this report.

Thermal Management

A combination of passive and active thermal management was used to ensure the Stratopigeon payload remained operational for all phases of the HASP flight. All components external and internal to the payload were specified and selected at an extended temperature range of -40-85° C, with the exception of the SSDs and SATA to USB interface PCBs.

The stepper motor was tested extensively due to concerns over the internal lubrication of the motor. A thermal chamber test was done on the UMD campus, testing the motor to -55° C. Motor failure occurred at -52° C, within the range of operation for the Stratopigeon at float altitude. All components on the control board, communications board, and battery were selected and rated for extreme environment operation, negating the need for an active heating or cooling system.

Based on the data retrieved from the HASP 2010 Stratopigeon prototype, the current Stratopigeon data capsule is designed with minimal heat output. For the commercially rated devices, this means the colder end of the thermal management required an active heating system. A single 2W heater was placed between each SSD and the side of the box where it was attached, with a heat spreading device. These devices were successful in maintaining a temperature above -10° C, while external temperatures were measured at -50°C. Temperature was recorded during the flight and can be seen below.



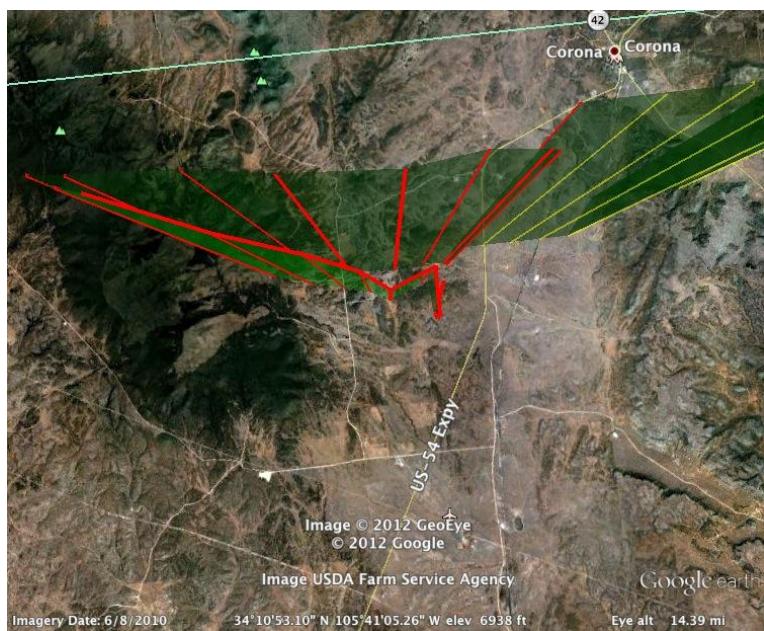
Based on the resulting temperatures, commercially rated solid state drives can successfully be used for high altitude flights of significant duration. In using commercial SSDs, more storage space at a significantly decreased cost is accomplished and a major factor in keeping the cost of the Stratopigeon capsule low.

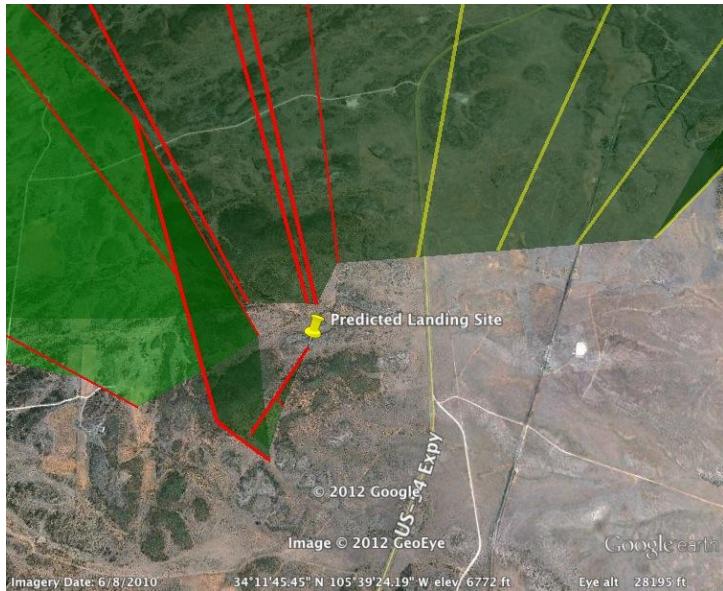
Detachment Path Prediction

A combination of the programs Balloon Track, MatLab, and Google Earth were used to make predictions about the flight path of the balloon and descent trajectory of the payload. Initially, a weather sounding file was loaded into Balloon Track, where flight parameters, such as duration, and cruise altitude, were set. This program would use the wind patterns associated with the sounding to give predicted ascent and cruise profiles of the HASP gondola along with the descent profile of the Strato-pigeon payload.

For the actual flight, this data was saved in the form of a KML file so that it could be tracked using Google Earth. The KML file was also run through MatLab in order to generate a descent profile anywhere the payload was dropped from. The function developed for this purpose used the assumption that the payload was dropped from 100,000 ft. and took inputs of latitude, longitude, and the filename of the data originally generated in Balloon Track to create this.

For the actual flight, the latitude and longitude coordinates input were the last coordinates that the HASP gondola registered the payload being attached to it with. This location, at 124,048 ft $34.6686471^{\circ}\text{N}$, $-105.4836925^{\circ}\text{W}$, was then input into the MatLab function and then generated an approximate landing location of $34.191528^{\circ}\text{N}$, $-105.664131^{\circ}\text{W}$. This was right outside of Corona, New Mexico, in Cibola National Forest. HASP flight data, in yellow, along with the predicted descent path of Strato-pigeon, can be seen below.





Ground Station Operation

Ground operations were divided into two groups; the base station and the tracking team. In order to simulate an Antarctic mission, the design of the payload system was such that the base station would receive packets from the 900 Mhz repeater while the data capsule was transmitting. The tracking team was able to hear packets directly from the data capsule itself. This way, even if the tracking team lost the payload signal, it would still be possible for the base station to locate it, and vice versa. The transmitters were turned on several times during flight while attached to the gondola and both tracking team and base station received packets at that time.

The base station was equipped with a 900 Mhz 14 dBi yagi and 30° beamwidth pointed at the balloon. This was attached to the dish used by CSBF to track the HASP payload. A serial to Ethernet bridge was used to attach the radio to the network at the base station such that received packets could be accessed wirelessly through the base station network.

Serial packets through HASP were successfully received throughout flight. There were no issues in the serial link through the HASP gondola.

Failure Analysis

A brief summary of the payload failure is as follows.

- The payload was turned on at altitude approximately 30 minutes before the drop. The repeater was turned on a short time later. Packets were successfully received by both the base station and tracking team.
- When the base station could not communicate with the tracking team, the tracking radio internal to the data capsule was inadvertently turned off and the payload was released.

Without a method of tracking the capsule, the exact location of the capsule on the ground could not be determined.

Improvements in operations and software techniques could be used to mitigate future similar failures. Changes to software development and operational procedures for the Stratopigeon payload are necessary for successful and reliable operation in an Antarctic environment.

Software

Soft checks when writing software, in particular for mission critical operations, are necessary to avoid unseen circumstances and possible human error. Due to the small nature of the UMD HASP team, this aspect of the software development was not emphasized. For example, a program that accepted a payload release command if and only if the payload radio was turned on would have been productive. Several other safety commands that are possible include:

- Do not drop or manual override only release condition on GPS no lock state
- Do not drop on radio powered off condition
- Do not drop or manual override only on repeater off condition
- Automatic on command to radio power if the drop command is issued
- Automatic on command to repeater power if the drop command is issued

It is important for more than one team member familiar with the software to check for missing conditionals, especially flight critical ones. With such conditionals in the software, as many as can reasonably be considered, a failure such as the loss of the payload can be avoided.

Operations

Many of the combined reasons for the loss of the data capsule reside in operations and management. During the hang test for the payload, a full run-down of the payload release was necessary, by the base station manager, with no external input from the rest of the team. As the hang test payload detachment was a far shorter and hasty operation than the flight release, many of the conditions that occurred in flight were not encountered. This could have been avoided with a more thorough practice run.

Also considered would be a full payload brief for the tracking and base team before the mission operations. While all of the team members had been involved with the payload for a good amount of time, a mission brief, including critical components for flight ops, would be useful. This time would give team members, particularly the tracking and base station operators, a chance to clarify critical uncertainties. Again, due to the small size of the team, this was not considered when it would have been useful. A detailed checklist with this mission brief is also necessary. A second member at the base station, as there was only one this year compared to prototype testing in 2010, would have also been useful to confirm payload procedures and provide a second perspective under pressure.

Lack of communication between the base station and tracking team also caused payload recovery to be unsuccessful. Because both teams would be receiving payload location, it was thought that cell phone coverage would be sufficient to pass critical information. During the flight, cell phone coverage was inadequate for the task required. A different, more reliable method of exchanging information is strongly recommended for future operation, even further than the ham radio used in 2010, also somewhat unreliable. A satellite phone or other method of radio communication would be useful.

A list of suggested operations improvements are the following.

- Detailed mission brief before the flight
- Detailed checklist for tracking and base station teams
- Full run through of payload procedures during hang-test by the base station team only
- Reliable communications method between base station and tracking team
- Flight checklist, for pre-flight and during flight ops
- Two team members each for the tracking and base station teams

Future Work

The Stratopigeon concept is an important supplement to current Antarctic ballooning techniques and has great value for ULDB flights. Further design development can improve this value extensively. In continuing payload development, the Stratopigeon team suggests the following:

- A water-landing payload. Dropping the payload over land, as in its current design, is limiting in where the payload can be released. A payload that can be released over water and retrieved by boat expands the operational capacity of the capsule.
- New sizing: Digi now makes very small radios that can perform all the functions of those used in the 2012 test. Combined with large amounts of storage now available in very small packages (micro-sd cards for example), the Stratopigeon payload could be reduced to the size of a pack of cards.
- Improved universal interface to research payloads. Given that each research payload is different and has different data storage needs, a universal easy to use data interface to the Stratopigeon payload is required.