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EMBRRY-RIDDLE AERONAUTICAL UNIVERSITY
PRESCOTT, ARIZONA

HASP 2013: Hatchling II

An investigation into atmospheric gas sampling and testing the preliminary design of a cube satellite

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ABSTRACT

Flown on the 2013 HASP high altitude balloon flight, the Hatchling II payload from Embry-Riddle Aeronautical University's Prescott, Arizona campus sought to investigate the prevalence of wildfire smoke in the stratosphere through its "Phoenix" module, while also testing an early version of "EagleSat", the first student-built satellite from the campus.

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MISSION BACKGROUND

Hatchling II was developed as a dual module payload: The science payload, called *Phoenix*, would investigate the presence of smoke particulates in the upper atmosphere; and the engineering payload, *EagleSat*, would be a test article of a future cube satellite. The two halves of the payload would operate independent of each other, only connecting to each other at the power input from the HASP platform. Independent operation would allow the *Phoenix* module to focus all processing power to sampling the atmosphere while *EagleSat* ran its own routines to check the integrity of the components.

Wildfires are a perennial plague for the western half of the United States, with larger and larger fires developing with each passing summer. The effect of these fires are typically only felt in the troposphere, as the tropopause, the boundary between the troposphere and stratosphere, is incredibly stable and effectively isolates the two parts of the atmosphere. However, extremely large and energetic wildfires have the ability to push smoke through this boundary, thus releasing excess carbon dioxide, carbon monoxide, water vapor, and even smoke particulate into the stratosphere. However, it is not known exactly how often smoke is able to puncture this boundary, nor the quantities of smoke that persists in the stratosphere. The *Phoenix* payload was designed to investigate this phenomenon, flying multiple times during the year to compare data from before the peak of fire season, during the peak of fire season, and once fire season had subsided. Comparing this data would offer an idea of just how the composition of the stratosphere changed in relation to wildfires.

EagleSat is a student-led satellite development project slated to launch in 2016, and was awarded its launch slot through NASA's CubeSat Launch Initiative. *EagleSat* was designed to investigate the effects of solar radiation on computer memory in low Earth orbit, as well as to study how the orbit of a cube satellite decays over time. The radiation tests were planned to take place by comparing the data stored in the computer memory to that stored on radiation hardened memory, which would serve as the control in the experiment. Any differences in data could then be compared to radiation data, and if any correlation could be found it would be labeled a Single Event Upset (SEU) and noted to which memory type the error occurred. For measuring orbital decay, it was planned that an onboard crystal radio, tuned to the frequency of the radar beams associated with the Air Force's Space Surveillance System, would be used to measure the time it took the satellite to complete one orbit over the United States. However, with the decommissioning of the Space Surveillance System, this payload module has since changed to incorporate a GPS module to gather position and velocity data, which will in turn be plotted and compared to a model of the expected descent. This data could prove to be useful with the advent of CubeSats, as it will offer a better idea of just how long these small satellites will persist as obstacles to be avoided in low Earth orbit.

MISSION OBJECTIVES

For the 2013 HASP flight, the *Hatchling II* payload was to test the scientific goal of the *Phoenix* module, while running tests on the *EagleSat* module to verify the integrity of the test article. The two would be mounted together, though they would operate separately so as to better achieve their goals.

Phoenix would be sampling for carbon dioxide, carbon monoxide, and nitric oxide, as well as checking humidity, pressure, and for airborne particulates. The gases, all noted as byproducts of wildfire smoke, would be found through the use of gas sensors, while the humidity and pressure would be found through their corresponding sensors. Airborne particulate would be found through the use of an optical dust sensor, and would be greatly dependent on multiple flights to establish a baseline for particulate concentrations in the stratosphere. Running all components through all phases of the flight, however, would also allow for the team to create a representation of gas and particulate concentrations at all levels of the atmosphere, through the data collected during ascent and descent as well as at float altitude.

EagleSat, meanwhile, would be running as it would on orbit as it tested the strengths and weaknesses of the components installed onboard. The components to be tested would be a student-designed structure, an onboard computer, an electrical power system (EPS), solar panels, a radio and antennas, and backup batteries to power the CubeSat without input from HASP. The radio and antennas would send data directly to the team without first being passed down through HASP telemetry, this would allow the team to verify the status of the CubeSat in real time as well as send additional commands to check the link between the communications system and the computer. Flying the structure would have the advantage of testing how well it would hold up in the difficult thermal atmosphere in the stratosphere, where it would be exposed to sub-freezing temperatures but intense solar radiation. Testing the solar panels on the flight would allow for a verification of the triangular advanced solar cell (TASC) design, with their power input being monitored by both the onboard computer and the EPS' own processor. Testing the entirety of the subsystems at once would give the best analog to how the system would perform on orbit, and being able to do such in an environment so close to space for such a long duration would be a boon for the advancement of the *EagleSat* program.

PAYLOAD DESIGN

Phoenix Module

Given the dual-module nature of the payload, and the constraints imposed by the size of the *EagleSat* module, it was imperative that the *Phoenix* module be as small as possible while still maximizing the area available for the sensors to gather data. Thus, *Phoenix* was drafted in CATIA to be an aluminum box with a base of 14 centimeters per side, and a height of five centimeters. The aluminum was to be milled on a CNC, and had ports removed to allow airflow to the gas sensors as well as for the external temperature sensor to protrude from the structure. Also included were ports that would allow for the *EagleSat* module to fit onto the top of the *Phoenix*, as well as another port to allow wires to run between the two structures. The *Phoenix* structure was to be enclosed in a foam and fiberglass shell for thermal protection, a method which had been done by previous ERAU teams for protection and insulation on balloon flights. Internally, components would be supported and separated by a softer foam, which would help dampen any sudden impacts as well as isolate the components from any external heating or cooling.

Internally, the module was designed to contain a gas sensor array, two temperature sensors, a humidity sensor, two temperature sensors, an Arduino Mega, and an optical dust sensor. The gas sensors would be searching for carbon dioxide, carbon monoxide, nitric oxide, and ozone, which make up the major components of smoke. The challenge with these sensors would be establishing a baseline on earlier flights to allow for later data comparisons to see the impact of wildfire smoke on the stratosphere. The humidity sensor would be searching for elevated instances of water vapor, a byproduct of the combustion of organic materials such as trees or grasses, while the optical dust sensor would be searching for the soot that results from such materials combusting. The temperature sensors were to figure out the true effect of solar radiation on the payload, as preliminary balloon data from ERAU flights showed the temperature increasing beyond the tropopause. The external temperature sensor would be directly exposed to the sun and the exterior of the payload, while the internal temperature sensor would be encapsulated inside the foam interior of the payload, somewhat shielded from direct solar radiation. Having dual sensors would allow the team to investigate the effectiveness of the thermal shielding, and lead to possible areas of improvements for future flights. Basing the payload off an Arduino Mega would allow for simple programming, as it was a microcontroller that had been used for several previous flights, and it was easily made compatible with the various different sensors collected by the team.

EagleSat Module

The *EagleSat* module was designed to be a test article for all the progress that had been made over the course of the *EagleSat* program; being that the program had begun development ten months prior to the scheduled launch date, this was all extremely hypothetical at the time of proposal writing. At that time, it was thought that the HASP model of *EagleSat* would consist of a student built structure, solar arrays, antennas, a radio tuned to the amateur satellite band, a crystal radio for detecting the frequency that the Space Surveillance System operated on, an EPS, and onboard computer, and batteries to test those being sought for space operations. The goal of flying a nearly complete article was to offer a long-duration stress test in an environment not easily simulated in a lab environment: the low pressures could be simulated in a vacuum chamber, but not the varying strengths of solar radiation, or the sudden forces experienced at liftoff or landing. Being able to test the communications system over long distances is another advantage posed by flying on HASP, as the radios can be tested on campus, but range issues are only seen over long distances.

The *EagleSat* structure is a CubeSat-standard compliant, 10 centimeter cube made of 6061 aluminum alloy. The design was started by students in their senior capstone project, and has been continually worked on and improved by the members of the *EagleSat* project. The design was created with the idea of a stationary solar array, which is currently the plan for the orbital model of *EagleSat*, but does allow for deployable antennas. An early version of what may become *EagleSat's* deployable antenna system was included in the design for HASP, and during testing they proved to be quite strong and almost perfectly tuned for the task at hand. The antennas are made from trimmed measuring tape material, which lends them the necessary springiness to spring into place after deployment. For the HASP 2013 flight, however, this capability was not tested. The solar arrays flown on HASP consisted of multiple TASC cells mounted on a PCB, and through the harsh conditions experienced during the flight, the attachment method will be tested to see how well the cells hold onto the board, and how well they manage to continue to move electrons should anything happen to them. The EPS was designed by an Electrical Engineering student on the team, and is an incredibly promising design going forward, rivaling the best commercially available designs for a CubeSat EPS. The payload would contain a crystal radio tuned to the frequency of the Space Surveillance System, though testing with the actual radar would be unlikely. Therefore, the team planned on testing the radio via radio pulses from a handheld radio.

ISSUES ENCOUNTERED DURING PAYLOAD DESIGN

Phoenix Design Issues

Once design began on the *Phoenix* module, the most obvious problem became evident: Finding gas sensors that are sensitive enough to work in the upper troposphere and in the stratosphere is quite a task. Most gas sensors available for purchase are designed for finding larger than normal concentrations at sea level, which is orders of magnitude simpler than finding slightly elevated concentrations in the far less dense conditions of the upper atmosphere. For a test flight in March, prospective sensors were flown on a balloon flight in Arizona. Due to difficulties in locating all the sensors, only sensors sensitive to carbon monoxide were flown. The data returned from the sensors was disappointing – they were designed to be operated at much higher concentrations, and thus returned data from only the first few minutes of the flight. The search for new sensors led to only a carbon dioxide sensor that would be suitable to the conditions presented during the flight, thus removing the ability to detect three other trace gases and therefore generate a stronger set of data from future flights. However, the new, suitable carbon dioxide sensor arrived too late to be implemented into the final flight-ready payload, thus negating an integral part of the smoke-sensing experiment. Losing the gas sensor was truly disappointing, because it was such an integral part to the original science mission. Searching for these sensors, however, was an eye opening experience to just how difficult it is to search for trace gases in the atmosphere, and especially when operating under such size and power restraints.

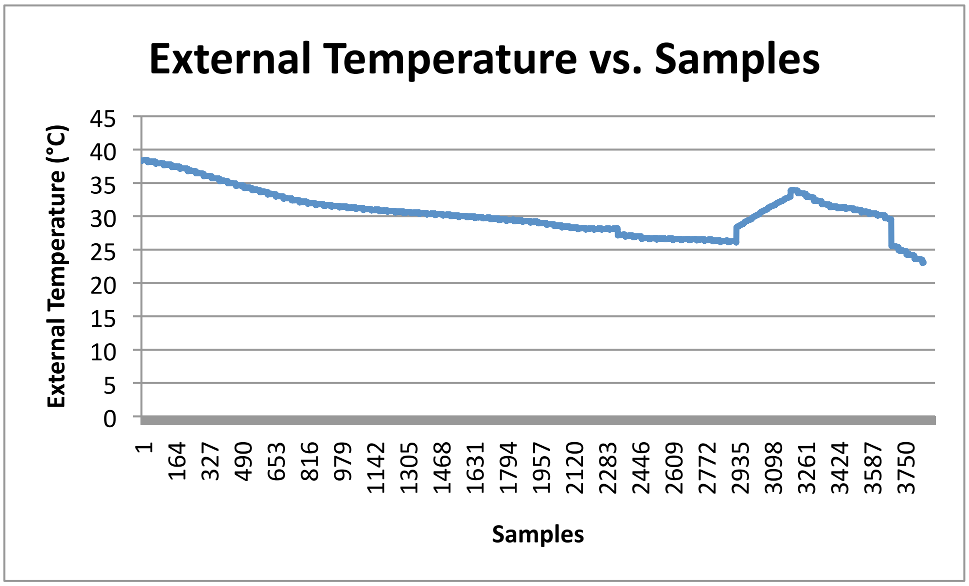
EagleSat Design Issues

The *EagleSat* design that flew on HASP, though it resembled that that was proposed in the initial proposal, was a much simpler and more realistic representation of the work that could be done in a semester. While the proposal included a fully feature CubeSat, ready to test its systems in the atmosphere, class schedules and design issues prevented that design from coming to fruition. Included on the HASP engineering model were a new integration board, serving as the interface between *EagleSat* and HASP and taking the place of the EPS; the radio and student-built antennas; the structure; and one example of a solar panel. Miniaturization of the original EPS proved to be an arduous task, and was not completed in time for the flight. The onboard computer was limited by a lack of programmers, and the flight hardware instead relied on the communications board for processing. The structure, though completed, lacked proper brackets for mounting the payload PCBs, though some were machined in time for the flight. Also, it was realized upon assembling the *EagleSat* article that assembly had not been considered when designing the structure, as attaching all the sides would have been an impossibility without self-tapping screws. However, even with these issues, *EagleSat* has shown considerable development over the past year, and because of them the project is stronger when looking towards the future.

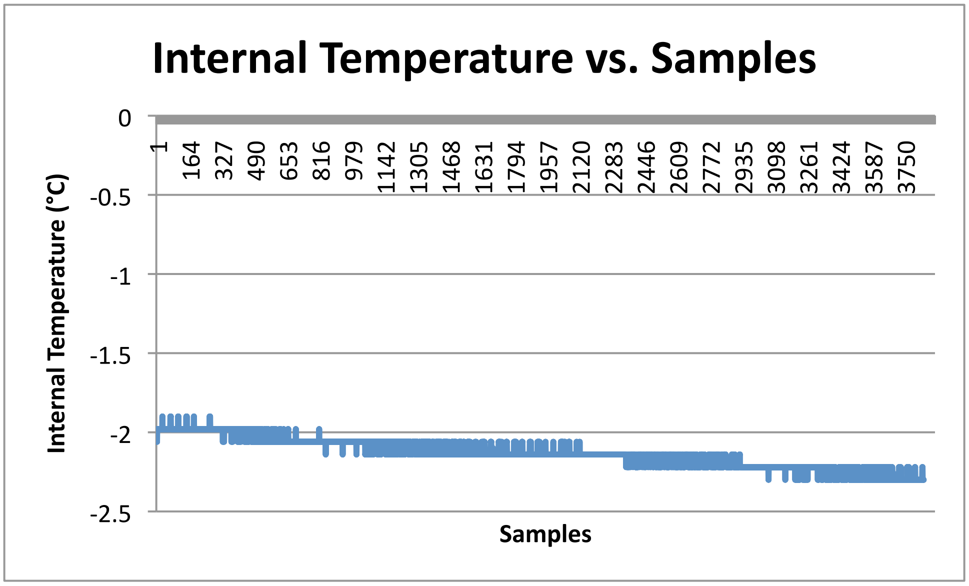
FLIGHT ANALYSIS

Phoenix Flight Analysis

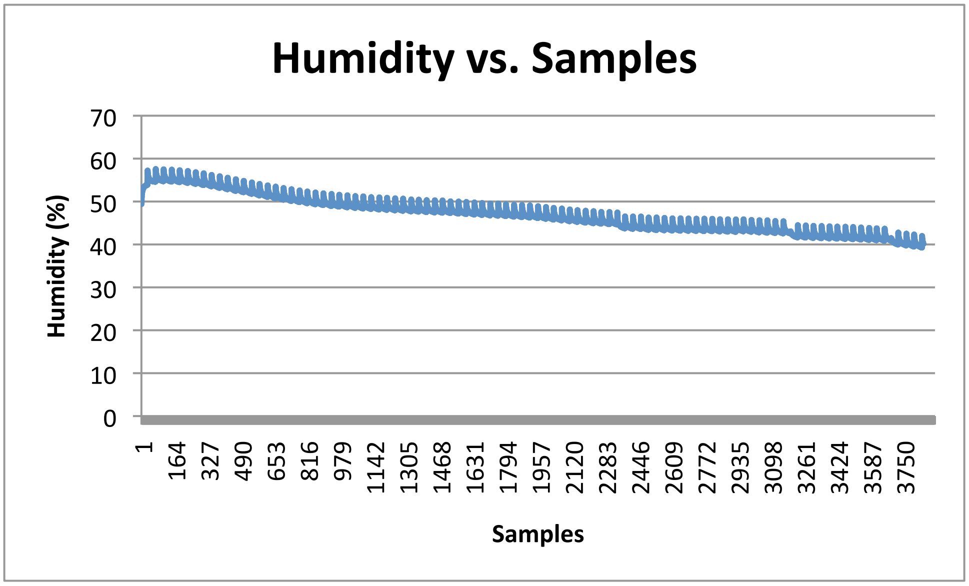
Phoenix's data was not entirely useable in analysis. The formatting of the text file caused some of the data to be unreadable and/or unrecoverable, unfortunately. Luckily, data from float altitude proved to be among some of that which was recovered, from where it was then analyzed with MATLAB and Microsoft Excel. Looking at the graph of the external temperature, displayed in Celsius, it is seen that temperatures showed a slight decrease, followed by a quicker increase. This is due to the solar radiation that the payload experienced during flight, heating up the exterior of the payload despite the relatively cool atmospheric temperatures. This pattern has been observed on other balloon flights conducted by ERAU, in which components on poorly insulated payloads have melted themselves to other components.



The internal temperature is very low due to the insulation that surrounded the payload which included space blanket on the outer perimeter, and foam inside the payload. Both of these materials have been tested on previous flights, and have been shown to be more effective than a solid insulator such as the foam and fiberglass shell that was originally proposed for the project. The space blanket allowed the payload to reflect a large portion of the solar radiation received, while the insulation kept the internal components at a temperature that would be expected for a mission in the higher reaches of the troposphere.



As for the humidity during float altitude, it is displayed as relative humidity, a percentage of the air that is water vapor. The graph shows a decrease in humidity during the flight. Looking at this data, it appears to indicate an increase in humidity as the payload begins to stabilize at flight altitude, hinting at possible condensation in the payload. Such condensation could be a result of passing through a cloud, or simply due to sources of water inside the payload itself. The data is higher than expected for almost all the stages of flight, leading to an interpretation that there may have been an issue with the sensor itself. However, as there is a decrease in humidity as the flight progressed, it appears that the sensor could have been working, just not to the accuracy that was promised. This may indicate that there are more specification that need to be examined for future missions.



Unfortunately, the pressure sensor and the optical dust sensor did not log any data. For the optical dust sensor, this likely due to the use of the part on previous flights, and undergoing natural wear and tear of hardware components. It was tested in the laboratory during development, and worked then, so other than the presumed causes, its failure remains a mystery. Post-flight examination of the sensor did not reveal anything other than a reluctance to power on. The failure of the pressure sensor can be attributed to a coding error, which failed to command the sensor to begin logging. This has been rectified should the sensor be used on future flights.

EagleSat Flight Analysis

Despite a failure on the communications board during the integration session in Palestine, TX, the *EagleSat* module performed flawlessly during the flight. The communications system worked throughout the duration of the flight, siphoning data from the *Phoenix* module to radio out over the amateur radio band via Morse code. For future revisions, this will be changed to packetized data, and the data will be coming from the *EagleSat* module rather than an outside source. The structure, despite its assembly issues, was able to hold together through all stages of the flight, and was still intact when it was recovered. Changes have been made to the design to address the issues found during HASP, and are ready for the manufacture of the next revision. The solar panels handled the thermal stresses without any issues, proving the design and attachment method to be solid and ready for use on further panels. The entirety of the flight was rather encouraging for the *EagleSat* program, and has shown what the areas needing to be addressed are.

FAILURE ANALYSIS

Given the difficulties faced by the *Phoenix* module, atmospheric sensing missions have been shown to be quite difficult to undertake. Finding sensors that are capable of working in the foreign environment found on high altitude balloon flights is quite a challenge, and one that was unfortunately not addressed for the payload until it was too late. The final carbon dioxide sensor was flown on a balloon this November, and was seen to be strong enough to have worked on HASP. However, for a future mission to be successful all of the sensors would have to be of this caliber, which would be difficult to acquire. Another item to be addressed for future atmospheric sensing missions would be the delivery of samples to the sensors – though the payload was designed with the goal of channeling air to the sensors, that task is quite difficult when the atmosphere is as thin as it is at float. A better delivery system would be crucial for a future atmospheric sensing payload. And finally, the data logger used on the *Phoenix* module needs to be replaced with one that is more effective. The data retrieved from the payload was quite unreliable, and despite the efforts of the team, only the data from one section of the flight was useable. Going forward, this needs to be rectified to allow the payloads to be wholly useful, and for every bit of data recorded to be able to complete the investigation tasked to the payload. It was frustrating to go through the data and find only two sensors worth of coherent data, especially on top of the lack of the main sensor.

For the *EagleSat* module, most failures faced were in development. This is an issue for a satellite being developed as an extracurricular project, and the team has made significant progress to make up for the lack of components available for what should have been a test flight of an engineering model. However, the components that did fly performed as expected, and are now on schedule for further development and integration into the CubeSat.

FUTURE WORK

Going forward, atmospheric sampling missions will face more rigorous evaluations before development begins. The concept behind the *Phoenix* module is an intriguing one, and one that grows more relevant with each passing fire season. However, without serious advances in the small gas sensors commercially available, different methods must be found to sample the atmosphere for trace particles of wildfire smoke. Also, if such a mission were to be repeated, it is unlikely that it could successfully share space with a second payload module. To better expose the sensors to the environment would require more space, and with a cube satellite sharing the space, that is simply not possible.

After extensively analyzing the flight data, it was obvious that there were difficulties in taking the recorded data and logically interpreting it. It is recommended that for future missions, changes need to be made for both logging and analysis. Logging methods need to be improved to the point where converting raw data to that which can be easily observed and understood can be done with minor difficulties, if any at all. This would require the logged data to be easily interpreted by Excel or Matlab, which is where data analysis fell apart for this flight. This problem will require a dedicated software individual on every team going forward, rather than another engineer moonlighting in the position.

For these reasons, the ERAU team has decided to step away from the atmospheric sampling payloads for the time being. Too many difficulties were presented during this flight, and before any similar payloads are presented, all of these issues will need to be fully examined. Therefore, focus for future missions is entirely on the *EagleSat* payload.

A proposal is being written for testing *EagleSat* on next year's HASP flight. A partial model of *EagleSat* was tested on this flight, and from that the team has gathered some insight as to what works and what areas need improvement. All of the components that performed flawlessly on the 2013 HASP flight will fly again. The solar panels will be able to power the payload for the 2014 flight, and a revised structure will be flown. Internal power regulation will be handled by the EPS, and tasks will be managed by the onboard computer. Thanks to the development cycle presented by the 2013 HASP flight, the *EagleSat* team is back on track to meet the 2015 delivery date, and hope to be present on HASP to test the payload once again.

Name	Gender	Ethnicity	Disabled?	Class Status	Year	Major
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Dallas Hodges	Male	White	No	Undergrad	Senior	Electrical Engineering
Aaron Petrek	Male	White	No	Undergrad	Junior	Computer Engineering
Cris Ricario	Male	Hispanic	No	Undergrad	Junior	Mechanical Engineering
Mo Sabliny	Male	Hispanic	No	Undergrad	Junior	Aerospace Engineering
Phil Riek	Male	White	No	Undergrad	Junior	Aerospace Engineering
Clayton Jacobs	Male	White	No	Undergrad	Junior	Electrical Engineering
Aaron Taylor	Male	White	No	Undergrad	Junior	Aerospace Engineering
Marcus Bever	Male	Declined to State	No	Undergrad	Sophomore	Aerospace Engineering
Dadija Bluidzius	Female	White	No	Undergrad	Junior	Aerospace Engineering
Kevin Jordan	Male	White	No	Undergrad	Junior	Electrical Engineering
Alex Collins	Male	White	No	Undergrad	Freshman	Aerospace Engineering
Steven Walton	Male	White	No	Undergrad	Junior	Space Physics
Michael Matyas	Male	White	No	Undergrad	Junior	Aerospace Engineering
Lisa Ferguson	Female	White	No	Undergrad	Sophomore	Electrical Engineering