Polar Launch

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Abstract

Recent studies indicate the presence of microbes at high altitudes in the Earth's atmosphere. During a NASA six-week hurricane research mission in 2010, 314 different types of bacteria were discovered. The Polar Launch team is interested in characterizing the trends observed in microbial diversity as a function of altitude. Developing a more detailed understanding of atmospheric biology will aid in models which predict cloud formation and long-range bacterial transport across the globe.

The goal of this project is to launch a high altitude balloon into the upper atmosphere, reaching altitudes of approximately 75,000 feet. A student-constructed device will collect data on the different types of microbes existing at various altitudes. While making this balloon, the students will try to make connections to high school and middle school STEM subjects.

Problem Objective

The purpose of the Polar Launch team is to design, build, integrate, and launch a reusable payload capable of collecting air samples at high altitudes to study the diversity and range of organisms at different altitudes. The payload will be attached to a weather balloon and samples will be collected 4-5 times throughout the ascent. The payload must survive impact and be successfully retrieved. Biology students will analyze and identify the microbial content trapped within the air samples.

Literature Survey

Before solutions and ideas for the project were established, research was conducted on similar weather balloon launches and the data obtained from them. The most applicable project found was from a team at Georgia Institute of Technology.

The goal of the Georgia Tech team was to study high altitude bacteria and their impact on weather, climate, and long-distance disease transmission. Also, it is known that bacteria has a role in forming ice and they want to investigate whether certain types of bacteria are more likely to survive at high altitudes than others. Sampling was conducted aboard a DC-8 aircraft over both land and water at approximately 33,000 ft. Two sampling lines were used which pulled an average volume of 6 m^3 over 4 parallel Whatman cellulose nitrate membranes using a vacuum pump. "Handling blanks" were also inserted into lines with no airflow.

The samples were analyzed using genomic techniques including polymerase chain reaction (PCR) and gene sequencing instead of conventional cell-culturing techniques. Seventeen different taxa of bacteria were found along with small traces of fungi. Also, as expected, samples over the ocean produced higher levels of ocean spray organisms while land samples produced more land organisms [1].

The results of the Georgia Tech team are encouraging. The Polar Launch team is also looking into using a vacuum pump for sampling. The use of a blank chamber may be useful to create baselines at different heights and ensure cross-contamination between different atmospheric regions has not occurred. It also may be interesting to conduct a balloon launch near hurricane season to study the effect storms have on dispersing bacteria into high altitudes.

The main difference between this study and ours is that we will be using a weather balloon to collect samples instead of an aircraft. Sampling from weather balloons instead of an aircraft has its advantages and disadvantages. One advantage of the weather balloon is that it will be able to climb three times farther than the DC-8 aircraft, which can only reach a maximum height of approximately 41,000 ft. A disadvantage is that multiple samples will not be able to be collected at a constant altitude since weather balloons climb continuously. Another disadvantage is that samples cannot easily be taken over the ocean with a weather balloon.

Additional research was conducted on how high altitude balloons work. At the most basic level, these packages operate with a balloon and parachute. The balloon is filled until the payload is able to be suspended. Then, depending on the type and size, the balloon will climb to a maximum altitude ranging from 60,000ft to 105,000 ft. when it expands to more than four times its original volume and bursts due to decreased pressure. The parachute then deploys and the package falls back down to earth [2].

Most balloons are filled with helium but hydrogen may also be used. Helium is currently much more expensive than hydrogen. However, extensive care must be taken when handling hydrogen since it can be flammable and explosive [3].

Articles and actual balloon launch videos also provided insight on conditions necessary to launch the balloon. These conditions, along with laws and Federal Aviation Regulations (FAR) regarding balloon launches, are reflected in the criteria and constraints below.

Marketing Requirements

The marketing requirements of this project are as follows. The module must collect air samples in the Troposphere and Stratosphere at various heights ranging from 7,000 ft. to 80,000 ft. The module must be able to record altitude, latitudinal/longitudinal position, temperature, humidity, and pressure.

Criteria

The criteria of the project are as follows. The inside of the module must be easily accessible for adjustments or repairs. This will be important because the filters will need to be easily accessed for insertion and removal, the SD card will need to be accessible to retrieve environmental data, and repairs may need to be done in the field. The module must be self-powered because no external power supply will be available. The module must prevent contamination before launch, between samples, and after landing. This will be imperative to maintain accurate representations of the microbial diversity in the atmosphere. The module must be reusable. This will be important if multiple flights are needed or if this project is further carried out by future engineering capstone groups. The module must be able to be successfully tracked and retrieved. The module must be modular, so different experiments can easily be run in the future.

Realistic Constraints

The realistic constraints are as follows. The package must meet the following FAR standards [4]:

- Total device must weigh less than 12 lbs.
- Individual modules must weigh less than 6 lbs.
    - If modules weigh more than 4 lbs., they cannot have weight/size ratio of more than three ounces per square inch on any surface of the package (determined by dividing the total weight (oz.) of the payload package by the area (in^2) of its smallest surface)
- Payload rope must break at an impact force of less than 50 lbs.

The module must successfully operate in temperatures that reach -50° F and winds in excess of 100mph.

Objective Tree

The objective tree was broken into four main topics: cost, reliability, educational objective, and weight because these were determined by the group to encompass the major constrains and criteria established. While the educational objective is important and needed to be addressed, it is the smallest part of the project and received the lowest weighting out of the four categories. The rest of the weights were divided evenly among the reaming three categories, cost, reliability and weight.

Reliability was then broken into three components: recoverable, component failure and potential contamination. The component failure was weighted the highest because if there are component failures, the data could become uncollectable and the objective of the balloon will not be able to be reached. However, it is still important that the device remains recoverable and there are no potential contaminations. If the data collected is contaminated, all of the data could potentially be lost.

The objective tree can be found in Appendix A

Educational Aspect

Ohio has recently adopted the new Mathematics Common Core standards. These standards are attempting to replace the state standards on a national level. These new standards present new and aspiring teachers, along with experienced teachers with difficulties. Interdisciplinary lessons are harder and harder for teachers to make time for. This means that the lesson plans need to cover more material and tie into more subjects.

To incorporate education into the project, we created an interdisciplinary unit lesson plan using the new 7th and 8th grade Common Core Mathematics Standards. In this lesson, we incorporate teaching about the different levels of the atmosphere, microbiology, creation of expressions, ratios and geometry. Since the licensure for Engineering Education majors is in Mathematics, we focused on the mathematical aspects. To aid these lessons, we created interactive web modules for the students and the teachers to use. The teachers will be able to gain an understanding for all of the material that they may not be familiar with on these web pages. The students will be able to use technology in a productive way in the classroom. We plan on having the students do hands on labs and discover their own knowledge through these labs. We will be able to actually use this unit lesson plan in the spring of 2014 when one of the team members is student teaching at a local middle school.

Another educational aspect of the project will be to have either a test launch or an actual launch as a community event. While there, a brief introduction will be given to the students and handouts will be made available telling the kids about the science, technology, engineering and math behind the balloon.

Alternative Solutions

The goal of the Polar Launch is to send a module up into the atmosphere to collect samples of the microorganisms up there. In order to accomplish this, there are several areas of mechanical design that need to be addressed. These include the method of transport into the atmosphere, the intake system, the intake port cover, the filter system, and the module's outer casing.

Finding a method of transport into the atmosphere was our first design challenge. One possible solution is to attach the module to an AIAA plane, climb to various heights, and collect samples. Drawbacks to this plan include the limited payload capacity of the plane and the restriction on altitude. The other possible solution is to launch the module via weather balloon. The weather balloon would be able to reach and exceed altitudes described in the NASA problem statement. However, one drawback is that the balloon would does not dwell at the maximum altitude, meaning that data could only be collected over altitude ranges and not at a specific altitude.

The air intake system on the module must pass a sufficient amount of outside air through the filters to obtain the necessary amount of samples to analyze. The first possible solution is to have a small air pump passing outside air through the filter. The problems with this solution include determining the amount of air that will be able to be transported through the filter, if the pump will be able to operate at the decreased pressure and temperature of the upper atmosphere, and if an on board battery will be able to power it through the entire duration of the flight. The other solution is to create a nozzle with an intake at the top of the module with a large surface area leading to the air filter that has an intake with a small surface area. The air's exit path could then open up again creating room for a fan to help draw air through the filter. The fan, however, may not need to be there if the upward velocity of the module is enough to pass air through the nozzle with sufficient velocity. It is also unknown how much the air filter will restrict air flow through the nozzle. Regardless of which of these solutions we use, there is still the issue of contamination at the intake.

In order to prevent contaminating our samples before reaching the required altitude, an intake cover needs to be designed that will only open when the correct altitude is reached and close when the module is done collecting samples. The first idea to accomplish this is to have a small electrical motor in the capsule that will have a pinion moving a rack laterally to open and close a door at the proper altitude. The second potential method is to have a servo motor operating a revolving door that covers the intake. The motor would turn the cover a number of degrees to uncover the intake, and then turn it back the same amount to cover the intake back up.
There are many different possibilities for designing the filter system. The first possibility is to have a single filter fixed in place in the module prior to flight and only take one sample per flight. This means that a new weather balloon would need to be used to collect each sample from each altitude of interest. The next possibility is to have a series of filters arranged in a circle revolve in order to put a new filter in place for the next altitude of interest. This would give us a good number of samples in one flight, however it could pose issues of contamination seeing as the filters would be using the same intake since the intake could be contaminated from collecting previous samples. The last possibility is to have several separate intakes altogether and have their respective covers open when the proper altitude is reached. This would potentially add a lot of weight to the module, but would be good for collecting samples with the least amount of contamination possible.

The last area of design needed to be covered is the casing of the module itself. This component will be extremely important as it will protect all of the electrical and mechanical components of our module from the low temperature and pressure of the upper troposphere and will protect them during landing. In order to protect our payload, the casing should have the following properties associated with it: insulating, durability to re-use the module, and cushion to dampen the landing impact. A good material for durability would be a hard plastic case, whereas Styrofoam and fiberglass insulation would be optimal for cushioning and insulation. Also, to dampen the impact with the ground, the module will be attached to a parachute to slow it down during descent.

The electrical design is diagrammed by the functional block diagrams, shown in Appendix B.
The payload employs a few environmental sensors to record the environmental conditions throughout the flight and the taking of air samples. These sensors include internal temperature, external temperature, pressure, and humidity sensors along with an accelerometer. These devices will be modules that serve as slaves on an I2C bus, while a microprocessor serves as the master. Inter-Integrated Circuit (I2C) is a serial single-ended computer bus that allows multiple low speed peripherals to be attached to a processor. I2C allows all of the devices to be chained together in a way that will make it easy to handle the number of sensors. A microprocessor, referred to as the data processor, will handle the data from these sensors.

A GPS module is needed to determine the location of the balloon while in flight. Most GPS modules are unsuitable for working at high altitude, as they limit their height to 60,000 ft, but a list of verified suitable GPS modules has been developed. Ease of interfacing to each and cost will be the most important parameters when deciding which module to use. The GPS interfaces to the data processor and an Automated Packet Reporting System (APRS) transmitter, if selected. APRS is explained later in this section.

Originally, a design that did not have a GPS was investigated, to save power and cost. This design relied on the pressure sensor to determine altitude. The biggest drawback of such a design is that we would be unable to transmit GPS locations when recovering the payload, hampering its recovery. The savings were negligible when compared to this drawback.
The only other inputs are controls sent to the radio receiver from the ground. These controls serve as a master override for controlling the mechanical sampling devices. They would only be able to be used in the event of an issue with the control algorithm, which will be well tested beforehand, but the bidirectional communication may be useful in launches for other experiments. There are no financial costs to adding this functionality.

All of the radios looked at operate in the ISM band. The industrial, scientific, and medical (ISM) bands are bands mainly reserved for non-telecommunication electromagnetic activity, but many radios that can tolerate this interference are available. Such activity in this band may result in less range of communication. This should not be an issue as most of the radios investigated have proven to be successful in 100,000 ft launches by other groups. The range of these radios will need to be investigated. Range, cost, and power are the most important criteria, in that order, for its selection.

Antenna selection will also be a very important consideration. Low dBi directional antennas can be used, along with standard omnidirectional antennas. The drawback of directional antennas is that the pursuit car needs to stay within the transmission of the antenna; with proper planning this can be mitigated. The issue with omnidirectional antennas is that, when vertically mounted, they will have a large null zone radius on the ground at high altitudes. Essentially, if we are directly underneath the balloon we may lose communication with it.

The radios would also be transmitting telemetry data back to the base camp and/or chase cars. This would include GPS coordinates, altitude, battery readings, sensor readings, and sampling status. This information can easily be configured to include any data of interest. This data also does not need to be transmitted very often, reducing the power consumed by the on-board radio.

The output data of the data processor is also written to an SD card. This serves as a backup, but will also record all of the data, whereas only mission critical data is transmitted between the payload and ground.

An off-board radio unit will be needed. This device needs to be compatible with the on-board unit. Another alternative would be to use an identical radio and a device to convert the output to USB. This decision will be made based on cost.

The experiment module consists of a microcontroller and the mechanical sampling controls. The sample processor will use a SPI, UART, or other protocol to communicate back to the data processor. Serial Peripheral Interface (SPI) and Universal Asynchronous Receiver/Transmitter (UART) are both common serial communication protocols. The sample processor will employ an algorithm to control sampling based on the acceleration, altitude, and override data sent to it by the data processor. The sample controls will be monitored by the data processor and this information will be sent back to the ground receiver.

Microprocessors, or microcontrollers, will need to support the required communication protocols. There are a wide variety of low-cost and low-power options that will likely support this requirement.

Battery selection is critical to the success of this project. Preliminary power budgets show that batteries with a capacity of at least 4 AHr should be sufficient, but once final components are selected this value will need to be adjusted. Backup power will also be very important. Such a system would provide power only to recovery-critical systems, ensuring the payload is successfully recovered, even if some functionality, such as the pump for the experiment, needs to be limited.

Interfacing these components will be a significant step, but a plan for this will be developed once components are selected. This step primarily involves programming the microcontrollers to communicate with each other, the sensors, and the other modules, such as the radio. The program code for the ground radio receiver/transmitter to interpret the data sent to it also needs to be developed. This ground radio will interface with a laptop to display the information to the user.

There are three major options for communicating once there is no longer line of sight between the base camp and/or chase car and the balloon. APRS communication is one proposed solution to communicate once the payload has landed. It consists of a series of repeaters organized by local HAM operators and has shown to be effective in other balloon launches [5]. It also directly uploads information to the internet, which may be useful in educational outreach activities. It is the most affordable option looked at, but does require a HAM license. It will also need to be verified that the balloon will land in an area with APRS coverage, though this is most of the United States. GSM communication is the other serious alternative. It would interface directly with the data processor. The modules are not very expensive, but they require a pricey SMS plan. They also rely on cell networks, so lack of coverage may be an issue depending on where the balloon lands. A final alternative is to use an extra off the shelf GPS device to transmit locations. This would be similar to the devices used by hikers. It is less precise than APRS, significantly more expensive, but should be highly reliable. These three designs are evaluated by the decision matrix included in this document.

Test Plan

The electronics modules will be tested for performance as they are constructed and programmed. These tests will cover the basics, such as ensuring they communicate with each other and verifying they have the functionality desired. This includes, but is certainly not limited to logging data to the SD card, transmitting and verifying reception from the radio receiver, verifying GPS coordinates from the backup system, and verifying the electrical controls for the sampling mechanisms.

The sensor will be tested under known environmental conditions, to ensure their operation. We will likely be unable to test all of them under expected conditions, so we may just have to trust manufacturer specifications. Measured GPS coordinates will also be tested versus known GPS coordinates. These coordinates will likely be determined using a smart phone, unless a more precise GPS device can be obtained.

The primary radio will be range tested on the ground. Basically, we will simply increase the distance between transmitter and receiver, until the signal can no longer be recovered. We do not expect to have the full range, due to lack of line of sight, but we should find that they function at a reasonable distance, likely around several miles. The backup system will also be range tested, if applicable based on design. Ideally, the signal strength will also be measured, during this test, by using a spectrum analyzer, but it is not a necessity if we cannot accommodate its use.

Individual pump and valve designs will be evaluated in the next few weeks. The biology department has suggested the use of a diaphragm pump and glass fiber filters and has donated samples to the team. The available pumps and filters will be experimented with to determine the needed airflow and power for the system.

The entire system will undergo a freezer test. Simply, we will place the payload in a freezer, and ensure the electronics still function beyond -50C. We have been offered the opportunity to use a freezer in the biology department, but it is at a static -80C. That is the only known freezer available for this testing at this time. We will be testing functionality of both, the primary radio and backup communication systems as well as the pump, valves and filters. The test will be performed with the designed heating elements for the final payload.

The case will also be impact tested with a 6 lb payload to ensure that it will protect the payload inside. We will accomplish this by placing a fragile material – possibly eggs or light bulbs – within the case and dropping it from various heights to simulate the maximum falling velocity of a 6 lb payload with a parachute. The rope used to connect the capsule to the balloon will also be tested to ensure that it meets the FAA standard of a 50 lb breaking capacity. This will be done by drawing the string taught and dropping a 50 lb weight into the center of the rope.

The group is also planning a test launch approximately a month before the actual launch to make final adjustments as needed.

Electrical Work Plan

ID	Activity	Description	Deliverables	Duration (Days)	People	Predecessors
1	Physical Circuitry					
1.1	Component Selection	Selecting components in the design. These will correspond to the functional block diagram	Parts List	28	Mike	-
1.2	PCB/Wiring Design	Design of circuit board and internal wiring	PCB schematic and Wiring Schematic	14	Mike	1.1

1.3	PCB Fabrication	Manufacturing the circuit board	Circuit Board	5	Mike	1.2
1.4	PCB Assembly	Placing and soldering circuit components	Populated Circuit Board	3	Mike	1.3
1.5	Wiring	Wiring of modular components	Completely wired Payload	2	Mike	1.3
2	Programming of Processors and Buses					
2.1	Control Algorithm Development	Developing algorithm for controlling sampling	Pseudocode for Algorithm	7	Mike	-
2.2	Data Processor	Programming of Data Processor; inputs, outputs, algorithms, etc.	Data Processor Code	3	Mike	1.4
2.3	Sample Processor	Programming of Sample Processor; inputs, outputs, algorithms, etc.	Sample Processor Code	3	Mike	2.1
2.4	I2C Bus	Configuring I2C Bus for the sensors and data processor	Functioning I2C code	12	Mike	2.2
2.5	Platform Output Stream	Configuring output bus for the data processor and input bus for sample processor	UART, SPI, etc. code	5	Mike	2.2
2.6	Radio Data Stream	Configuring radio receiver to send at desired bitrate, etc.	Operating Parameters for Radio Receiver/Transmitter	3	Mike	2.2
2.7	Configuring APRS	Interfacing APRS to the GPS and getting the module to send required data	Operating Parameters for APRS Module	3	Mike	1.3
2.8	Setting up Ground Radio	Developing code for ground receiver to understand the data sent to it.	Code for interpreting received data	7	Mike	2.6
3	Testing					
3.1	Freezer Test	Test Payload under extreme environmental conditions	Extreme Cold Test Results	1	Entire Team	2.8
3.2	Primary System Range Test	Determine maximum range of primary system on the ground	Range Verification	1	Mike, Liz, 1 ME	2.8
3.3	Secondary System Range Test	Determine maximum range of secondary system on the ground	Range Verification	1	Mike, Liz, 1 ME	2.8

Decision Matrices

The Decision Matrices can be found in Appendix D.

Mechanical Solution

FAR weight restrictions read that each box must weigh less than 6 lbs. and the payload as a whole must weigh less than 12 lbs. With these restrictions, it was necessary to create two payloads. The first contains the sampling system, including the detent ball sealing system, motor, pump, filters, tubing and tube fittings. The second capsule contains temperature, pressure, and humidity sensors, antennae, GPS, battery and electronics. The pump and motor in the first capsule are connected electrically via cables running through the center of each capsule.

Each capsule is box-shaped and based off a design by L. Paul Verhage described in a November 2013 article from *Nuts and Volts* magazine. The box is built from 1” polystyrene insulation board. This foam was chosen not only for its insulating properties, but also because it is lightweight and easy to work with. Nylon straps wrap up the sides of each capsule and attach them to the balloon and parachute. Electronics are anchored to sheets of polypropylene inside the capsule with nuts and bolts.

Air will be sampled at 4 different altitudes. To analyze variance between samples, three filters will simultaneously have air drawn through them at each altitude. Separate holes in the lid of the capsule lead to each filter to prevent cross-contamination. Springs, within the rotating disk press detent balls into each intake hole and seal on O-rings. One blank filter, present to determine the effectiveness of the sealing system and analyze possible contamination, will be used for a total of 13 filters and sampling lines. Tygon tubing and polycrystalline fittings connect the sampling lines into one tube which is connected to the pump. All tubing, fittings, and mounting components were chosen so that entire filter assembly may be autoclaved prior to the launch to kill all existing bacteria that may be trapped inside the sampling lines.

First Capsule: Sampling System: Rotating disk (red) is powered by the motor (yellow) which is attached to a shelf containing all of the filter holders (turquoise). Detent Balls seal on the stationary disk (blue). Tube fittings (clear) converge tubing towards the pump which sits on the bottom of the capsule.

Fig.1

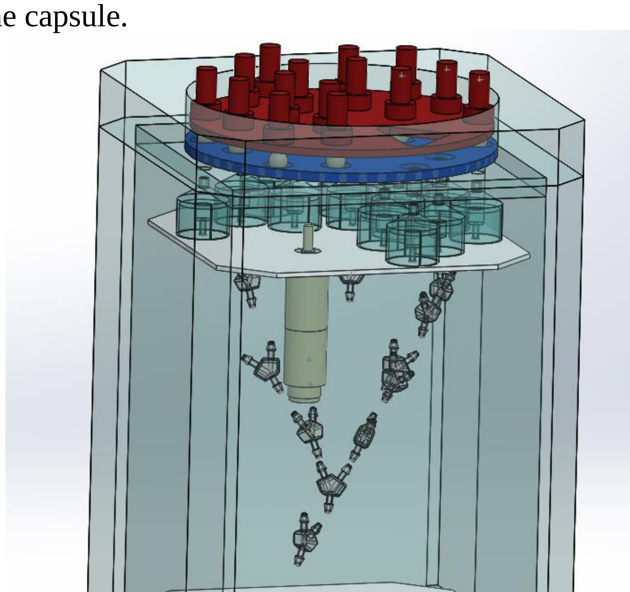
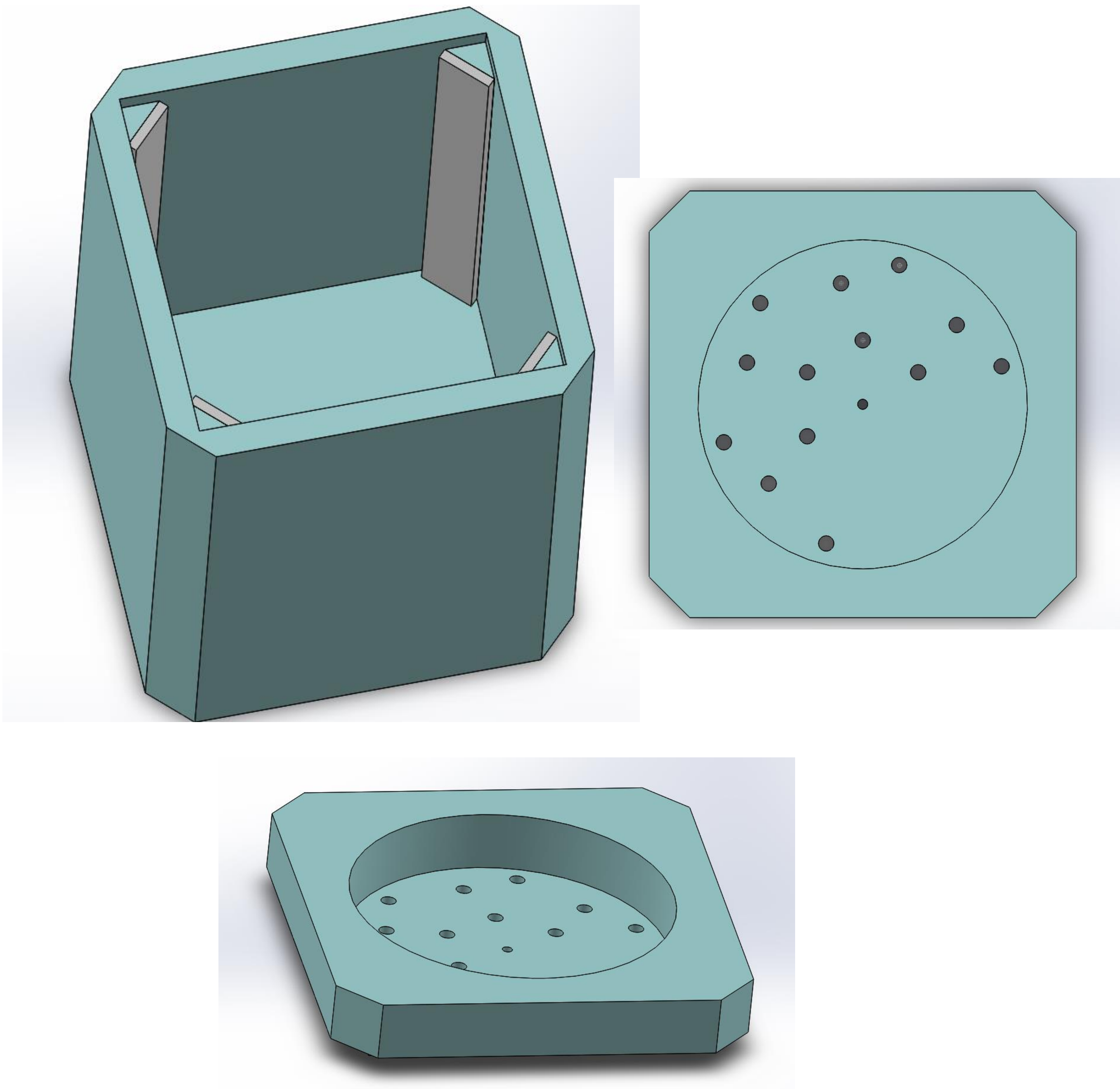


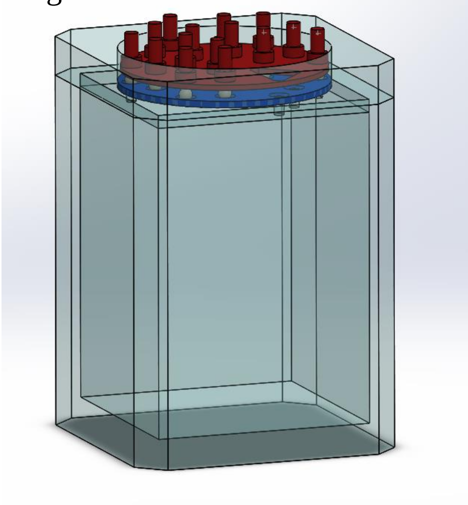
Fig.2

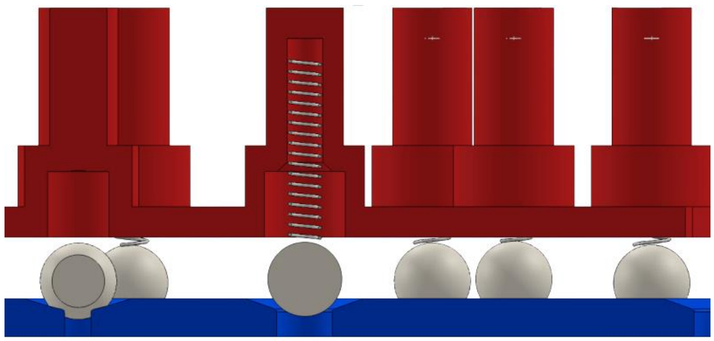


Detent Ball System:

The detent balls used to seal up the air intake holes are made out of a very hard polymer called Torlon. This material is commonly used in bearings and is extremely light given the strength. The O-rings that work in conjunction with the Torlon balls are made of Fluorosilicone, which can resist temperatures as low as -75 degrees F, which is an important quality for them to have seeing as the temperature in the stratosphere will get as low as -60 degrees F; even in the spring and summer.

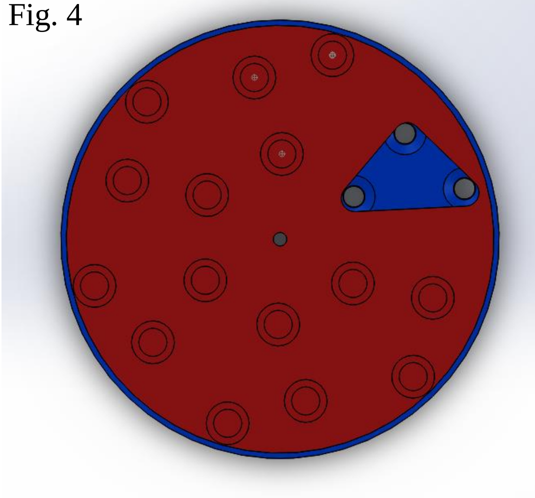
Fig. 3

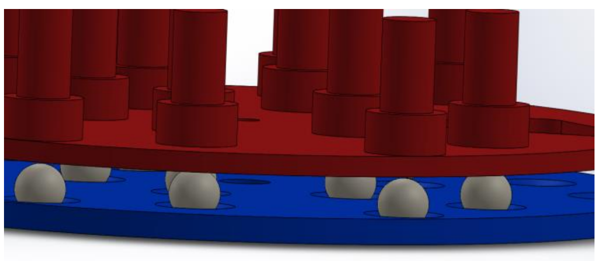




Sampling at one altitude: Detent balls seal against O-rings and springs are extended.

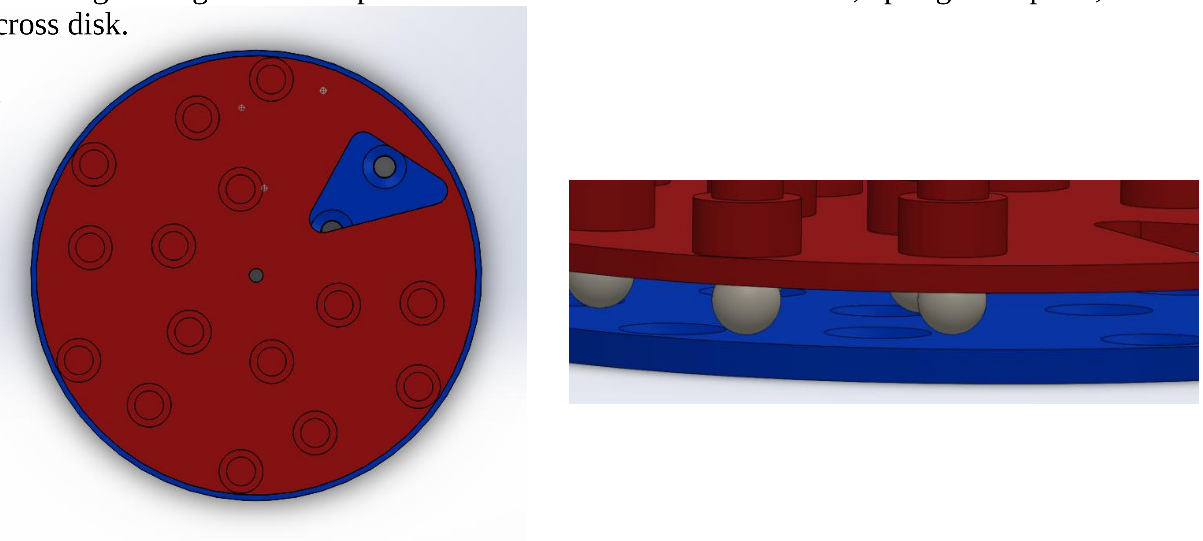
Fig. 4





Disk Rotating 60 degrees to sample at a different altitude: motor turns, springs compress, balls roll across disk.

Fig. 5



The motor that was picked out to turn the disk is a 12v dc gear motor with a planetary gearbox that provides a 51:1 gear reduction. The motor is also equipped with a digital encoder that can be used to accurately control the position of the disk as it reaches its sampling altitudes and rotates to uncover air intake tubes. Although the motor already comes with gearing, additional gearing of 5.625:1 is required to get the torque of the motor high enough to rotate the disk. While motors with higher gearing were available, they were not practical, seeing as the torque the motor was capable of exceeded the torque rating of the gearbox it came with. To prevent this, a custom gearbox with a 5.625:1 gear down ratio will be used to get the required torque without having any possibility of exceeding the torque rating of the planetary gearbox. The custom gearbox will be made of sheet aluminum and the gears inside will be made of Derlon, a very durable polymer. The output shaft of the gearbox will connect to the disk with a 0.25in. Steel output shaft. The shaft will be connected to the disk with two nuts and washers tightened on either side of the disk. Pins will also go through the disk and washers to help transfer torque.

Conclusion

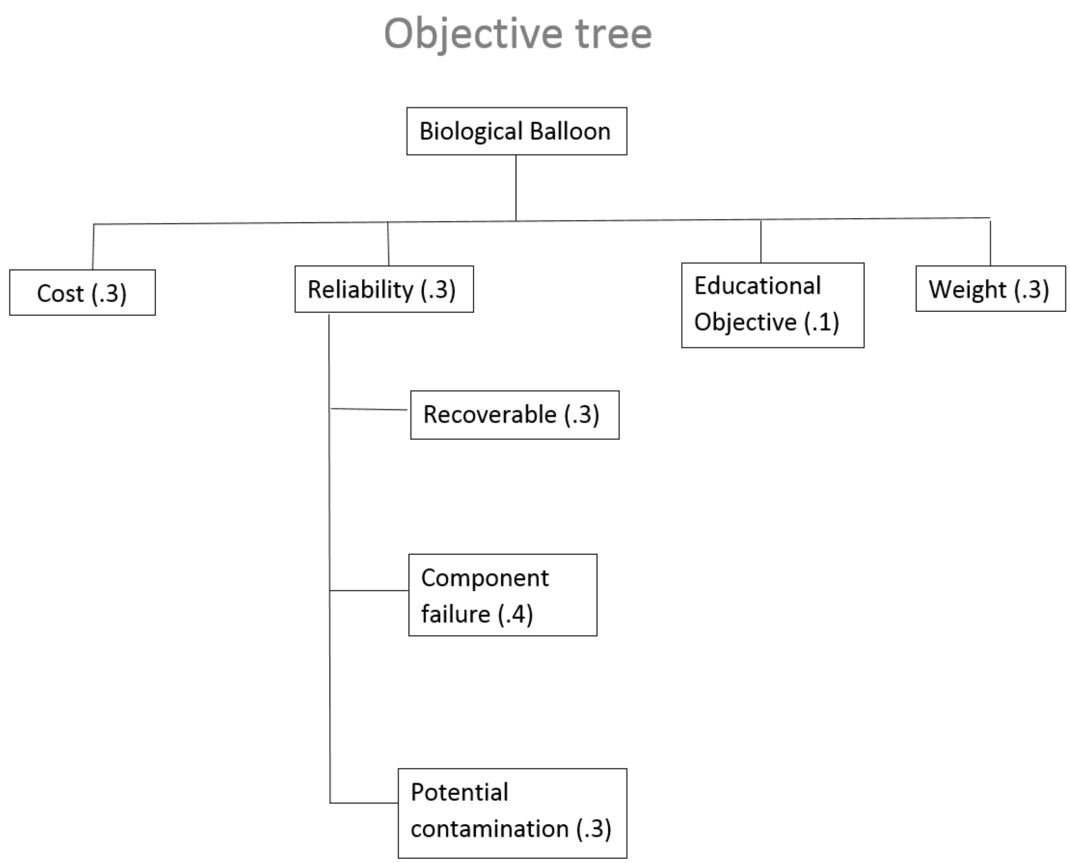
The Polar Launch team intends to meet the problem criteria by creating a module that is carried into the atmosphere via a weather balloon. The module will consist of five sampling tubes for each of the five sampling altitudes. Each tube will be connected to the exterior of the module and air flow will be controlled with solenoid valves. Glass fiber filters will be placed within the tubes and an air pump will pull air through the filters. A filter blank will be included inside the module to act as a baseline for bacteria growth.

Furthermore, the module will be encased using a lightweight Styrofoam box. Additional insulation may be added in areas to protect hardware from extreme temperatures.

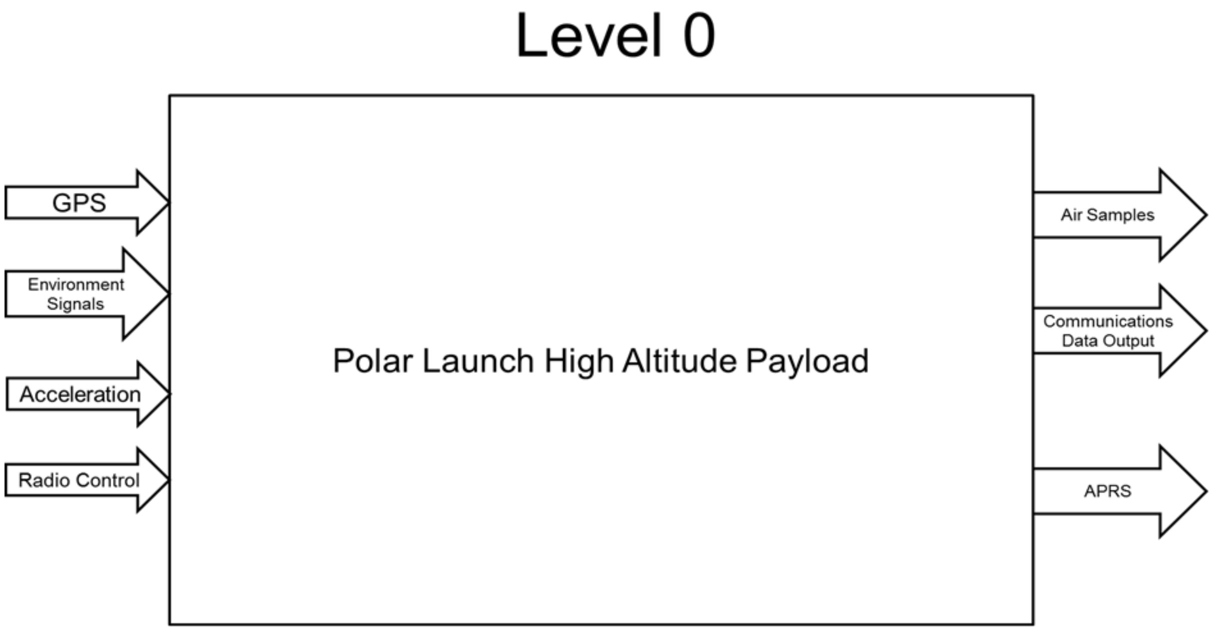
Sensors on the payload will record environmental data, including temperature, pressure, and humidity, along with telemetry data, including acceleration, altitude, and GPS coordinates. From this data, a control algorithm will control the sampling of the area. Override commands can be sent from ground to the payload, in case of any issues. While the payload is in the air, GPS coordinates, altitude, and the status of the mechanical controls will all be sent back to ground. This will allow users on the ground to know exactly what is going on. This will also aid in the tracking and recovering of the payload. A secondary tracking module will be on board. The type of this module is not determined right now, whether it is APRS or a secondary GPS, but we will ensure its successful operation in the expected geographic area.

The modules will be tested for functionality and successful operation in the expected environment. The maximum communication range will also be tested.

Appendix A: Objective Tree



Appendix B: Block Diagram



Module	Polar Launch HAP
Inputs	GPS Environment Signals Acceleration Radio Control
Outputs	Air Samples Communication Data Output APRS
Desc	Entire payload for balloon
Part #	N/A

Signal	GPS
Features	Communication from GPS sattelites

Signal	Acceleration
Features	Acceleration of payload

Signal	Environment signals
Features	Internal and external conditions (int. temp, ext. temp, humidity, pressure)

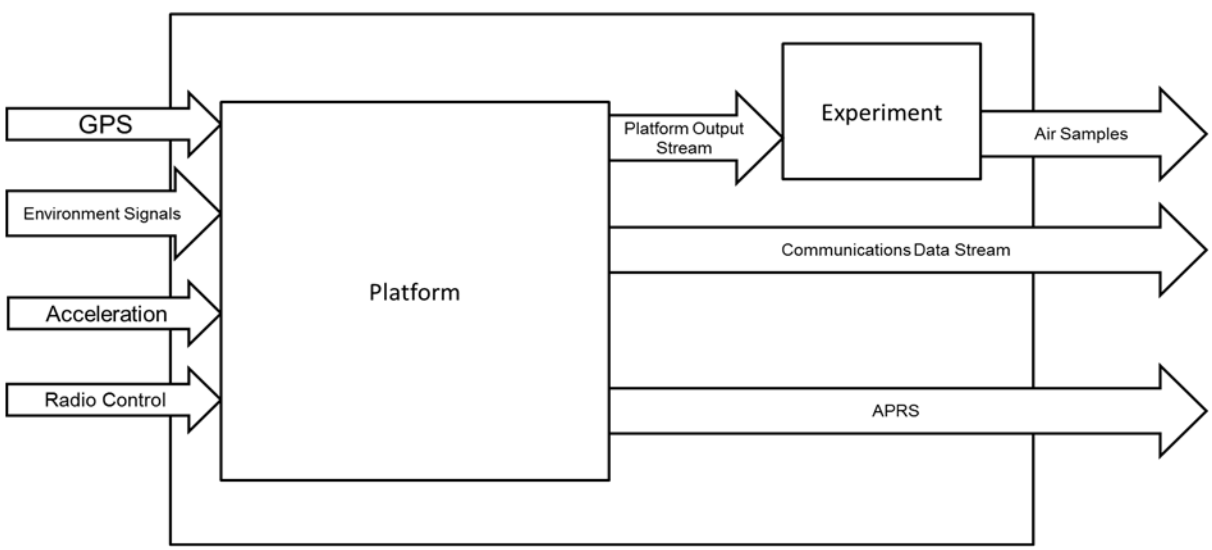
Signal	Radio Control
Features	Radio input from ground transmission Includes override of mechanical controls

Signal	Air Samples
Features	Collected air samples from experiment, using syringe filters

Signal	Communications Data Output
Features	Output stream back to ground (location, altitude, acceleration, status of mechanical controls, environmental conditions)

Signal	APRS
Features	Transmission of GPS coordinates, especially once grounded

Level 1

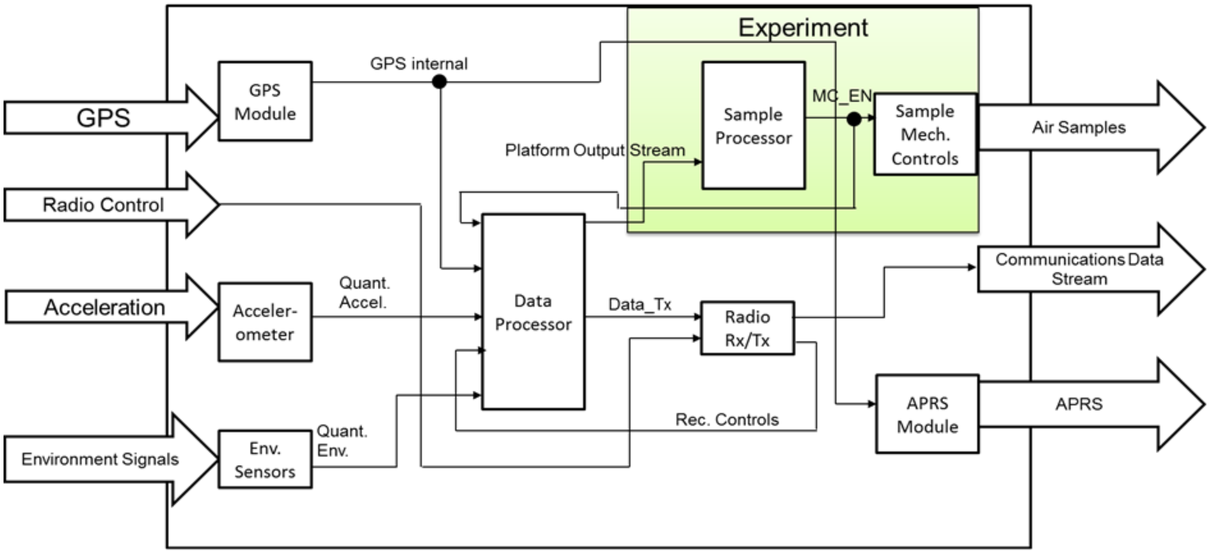


Module	Platform
Inputs	GPS Environment Signals Acceleration Radio Control
Outputs	Platform Output Stream Communication Data Output APRS
Desc	Launch/ Flight Telemetry/ Recovery Platform
Part #	N/A

Signal	Platform Output Stream
Features	Modular output between platform and experiment (data stream of altitude, override and acceleration)

Module	Experiment
Inputs	Platform Output Stream
Outputs	Air Samples
Desc	High Altitude Sampling Experiment
Part #	N/A

Level 2



Module	Polar Launch HAP
Inputs	GPS
Outputs	GPS Internal
Desc	GPS receiver module
Part #	

Signal	GPS Internal
Features	Usable GPS location data

Signal	Quant. Accel.
Features	Quantized acceleratio signal, possibly I2C or analog

Signal	Quant. Env.
Features	Quantized environmental signals, I2C, or possibly analog

Signal	MC_EN
Features	Enable sampling signals for valves, pumps, etc.

Signal	Rec. Controls
Features	Sampling override control signals received by radio receiver

Signal	Data Tx
Features	Data to be transmitted pre-modulation

Module	Accelerometer
Inputs	Acceleration
Outputs	Quant. Accel.
Desc	Quantizes Acceleration
Part #	

Module	Env. Sensors
Inputs	Environment Signals
Outputs	Quant. Env.
Desc	Takes environment conditions and turns them into I2C data streams
Part #	

Module	Data Processor
Inputs	GPS Internal MC_EN Quant. Accel. Quant. Env. Rec. Controls
Outputs	Platform Output Stream Data Tx
Desc	Takes all sensory inputs, monitors RX controls and mechanical controls and turns them into the required data streams. Serves as master for I2C
Part #	

Module	APRS Module
Inputs	GPS Internal
Outputs	APRS
Desc	Takes GPS location and transmits it using packet-based, repeater network
Part #	

Module	Radio RX/TX
Inputs	Radio Control Data TX
Outputs	Rec. Controls Output Data Stream
Desc	Receiver and transmitter module for radio communications. Includes antenna.
Part #	

Module	Sample Processor
Inputs	Platform Output Stream
Outputs	MC_EN
Desc	Takes processed override, altitude, and accelerometer data to enable certain sets of pumps and valves
Part #	

Module	Sample Mech. Controls
Inputs	MC_EN
Outputs	Air Samples
Desc	Based on input, enable acquisition for a certain collector, or none
Part #	

Appendix C: Budget

Item	Cost/Item	Quantity	Total Item Price
Balloon	$100.00	1	$100.00
Parachute	$55.00	1	$55.00
Filters	$25.00/pkg	1	$25.00
Valves	$8.00	5	$40.00
Hydrogen (per flight)	$40.00	1	$40.00
Styrofoam box	$6.00	1	$6.00
silicone airline tubing	$6.00		$6.00
Micro air pump	$32.00	1	$32.00
GPS module	$60	1	$60
Radio on board	$200	1	$200
Radio off board	$300	1	$300
Accelerometer	$28	1	$28
Temperature	$6	2	$12
Humidity	$7	1	$7
Pressure	$20	1	$20
APRS module	$40	1	$40
Radio Antennas	$60	2	$120
Battery	$20	1	$20
Electronics	$50	1	$50
Connectors	$50	1	$50
Total			$1,211.00

Appendix D: Design Matrices

Flow Control

	Solution	Disk		Valves		Moving Filters	
Criteria	Weight	Score	Points	Score	Points	Score	Points
Cost	0.3	60	0.21	50	0.225	55	0.2175
Weight	0.3	12	0.1875	20	0.1125	8	0.225
Reliability	0.3	5	0.15	7	0.21	2	0.06
Educational Content	0.1	5	0.05	6	0.06	4	0.04
	Total		0.5975		0.6075		0.5425

Backup Communication System

Criteria	Weight	APRS	GSM	Secondary GPS
Cost	0.3	90	60	40
Reliability	0.3	65	59	93
-Recoverability	0.3	50	30	90
-Component Failure	0.4	50	50	90
-Contamination	0.3	100	100	100
Ed. Objectives	0.1	100	70	70
Weight	0.3	90	95	88
Total	1	83.5	71.2	73.3

References

1. DeLeon-Rodriguez, Natasha. “Microbiome of the upper troposphere: Species composition and prevalence, effects of tropical storms, and atmospheric implications.” *PNAS* 2013.
2. Stratostar.net, “FAQ – High Altitude Weather Balloon.” Accessed 2 October 2013. <http://www.stratostar.net/faq>.
3. Linde Gas Company, “Safety Advice: 13- Handling of Hydrogen.” Accessed 20 October 2013. <http://www.abellolinde.es/internet.lg.lg.esp/en/images/Safety_Advice_13302_25939.pdf>.
4. Manes, Mike. “Excerpts from U.S. Federal Aviation Regulations (FAR): Part 101 related to unmanned free balloons.” Edge of Space Sciences. Accessed 20 October 2013. <http://www.eoss.org/pubs/far_annotated.htm>.
5. APRS Wiki, “ARHAB - Amateur Radio High Altitude Ballooning.” Accessed 20 October 2013. <http://info.aprs.net/index.php?title=ARHAB>.