SPS Chapter Research Award Proposal

Project Proposal Title	Roswell III, Space Balloon: Journey into the Stratosphere
Name of School	Purdue University
SPS Chapter Number	5781
Total Amount Requested	$1,321.84

Abstract

Purdue University's Society of Physics Students (SPS) conducted an investigation of the Earth's atmosphere by launching a space balloon during the Spring 2014 semester. The experiment utilized a balloon that would carry 4-6 lb. payload. This payload consisted of a GPS detector, radio transmitter and two cameras to observe both the Earth's surface and also to detect particles. Additional sensors attached to the weather shield of the balloon collected data on: altitude, pressure, and humidity. The space balloon was launched to reach a height of over 80,000 ft. or greater than 15 miles (~ 25 Km) and traveled over 60 miles before parachuting to the Earth.

The Purdue SPS chapter is now revisiting the project with focus on measuring atmospheric gas concentrations of pollutants and greenhouse gasses, aerial photography and reconstructing the design to administer improvements to the efficiency and effectiveness. In achieving this goal, we have established partnership with an engineering firm, HyperSight Imaging LLC, and faculty in the Department of Sciences that provide expertise and assistance. Ultimately our hope is to develop a replicable model for wider use around the globe for data acquisition of gas concentrations and to observe and compare any changes to the atmosphere from experiments last performed in the past late century.

Proposal Statement

Overview of Proposed Project

The space balloon project began with the focus of participating in the Global Space Balloon Challenge. The categories of this challenge are Best Photo, Highest Altitude, Best Experiment, Best Design, and Best Stories.

Purdue Society of Physics Students participated in the 2014 Global Space Balloon Challenge where we successfully launched Roswell II. This low budget craft successfully traveled to 83,000 ft collecting temperature, pressure, video and photographic data. During this project, initial designs for data acquisition and GPS tracking were developed. Now, SPS-Purdue is completely redesigning the payload to observe the concentrations of certain gases as a function of increasing altitude. We hope to implement new detectors designed to detect ozone, carbon dioxide, nitrogen dioxide, particulate matter (dust), sulfur dioxide, nitrous oxide, benzene, and carbon monoxide.

Our aim is to look for trends between these different gases and compare current concentrations with past concentration measurements. It is also notable that our research should be easily replicable and relatively inexpensive. It may be possible for other universities and even local high schools to take our model and perform these experiments leading to data collection of altitude dependent air quality over a larger span of earth's surface, not limited only to the Midwest.

Although gas concentration is our primary focus, we also have interests in adding cosmic ray detectors to our balloon payload. We are working to establish connections with Fermilab and its associated universities that are developing the next generation detectors which could be used to detect high energy particle fluxes with increasing altitude.

As we work on the project, it has and is opening up communication with both the scientific field as well as entrepreneurial businesses. Because of the nature of this project is being part of a global challenge, we would also have SPS connections with other schools and groups. This summer, we presented a poster of our results at the summer AAPT conference in Minneapolis.

After a successful flight and recovery, we now have a basis for further improvements for a more efficient flight and faster recovery time. More rigorous pre-flight testing such as an environmental testing chamber are now available to us for further pursuit of this project since word has spread of our accomplishment. We have opened communication with an engineering company called HyperSight as well as with more faculty in the Department of Sciences. Further creative ideas, valuable insight, and occasionally even resources are being offered which could lead to yet unperformed experiments leading to possibly even undergraduate publication.

Background for Proposed Project

The primary purpose of the space balloon is to detect and compare relative abundances of various gas species against altitude. Interestingly enough, data illustrating this relationship have not been collected since 1989. Instead, a plethora of experiments relating species abundance to time elapsed have been carried out. These data can then be contrasted with the data listed in table 1-1.

One very common measurement is the mixing ratio. The mixing ratio is the amount of moles of the certain gas per mole of dry air which is made of up of different constituents of different gases. Below is a list of the mixing ratios of gases in dry air.

Table 1-1 Mixing Ratios of Gases in Dry Air

Gas	Mixing Ratio (mol/mol)
Nitrogen (N2)	0.78
Oxygen (O2)	0.21
Argon (Ar)	0.0093
Carbon dioxide (CO2)	365×10^{-6}
Neon (Ne)	18×10^{-6}
Ozone (O3)	$0.01\text{-}10 \times 10^{-6}$
Helium (He)	5.2×10^{-6}
Methane (CH4)	1.7×10^{-6}
Krypton (Kr)	1.1×10^{-6}
Hydrogen (H2)	500×10^{-9}

A superior description is given by the source of this table:

> “The mixing ratio CX of a gas X (equivalently called the mole fraction) is defined as the number of moles of X per mole of air. It is given in units of mol/mol (abbreviation for moles per mole), or equivalently in units of v/v (volume of gas per volume of air) since the volume occupied by an ideal gas is proportional to the number of molecules. Pressures in the atmosphere are sufficiently low that the ideal gas law is always obeyed to within 1%.
> The mixing ratio of a gas has the virtue of remaining constant when the air density changes (as happens when the temperature or the pressure changes). Consider a balloon filled with room air and allowed to rise in the atmosphere. As the balloon rises it expands, so that the number of molecules per unit volume inside the balloon decreases; however, the mixing ratios of the different gases in the balloon remain constant. The mixing ratio is therefore a robust measure of atmospheric composition.” [1]

A comprehensive compiled listing of atmospheric mixing ratios of gases was completed in the late 20th century. Since then, experiments have scarcely been performed to validate or compare more recent atmospheric changes to the graph displaying mixing ratios shown in Figure 1.

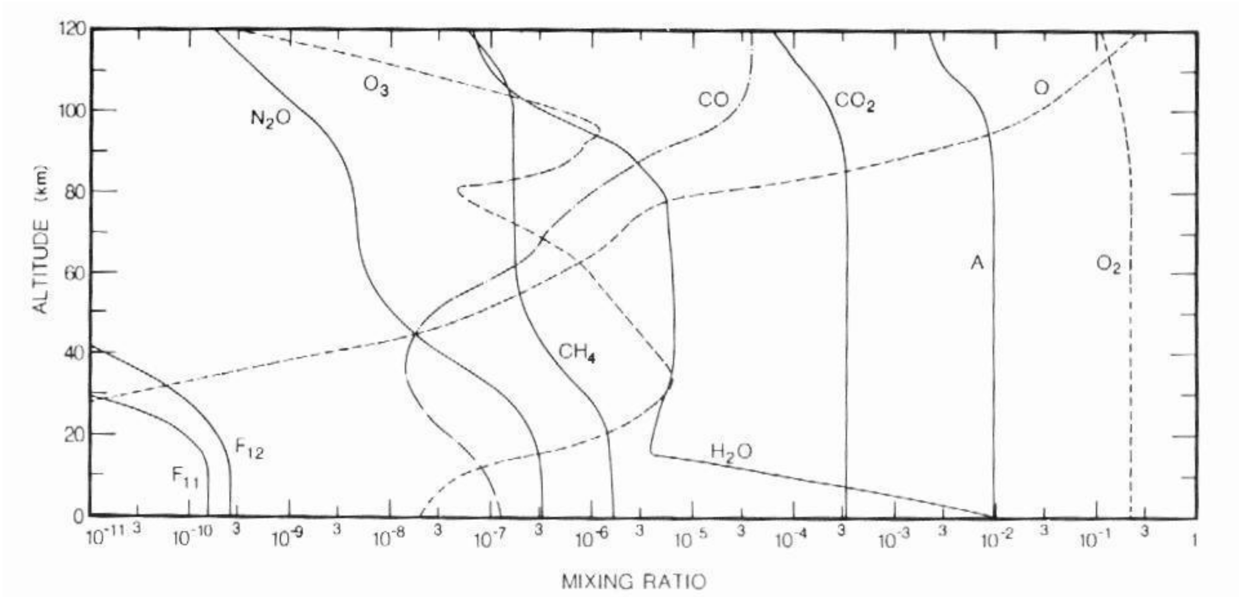


Figure 1**:** Vertical profiles of the mixing ratios of selected species at the equinox (from Goody and Yung, 1989).

Another relatively unavailable measurement is a complete atmospheric profile to ascending altitude. Although ozone concentration is expected to peak at a certain altitude as illustrated by Figure 2, the specific composition of the gases are typically not represented in such a graph of altitude plotted against concentration. For instance, carbon dioxide concentrations are rarely measured against altitude. Rather common graphs of carbon dioxide represent the concentrations to a time scale. It would be interesting and intuitive to find how various gas concentrations changes particularly in altitudes ranging from 10,000 ft to 115,000 ft (3 km to 35 km).

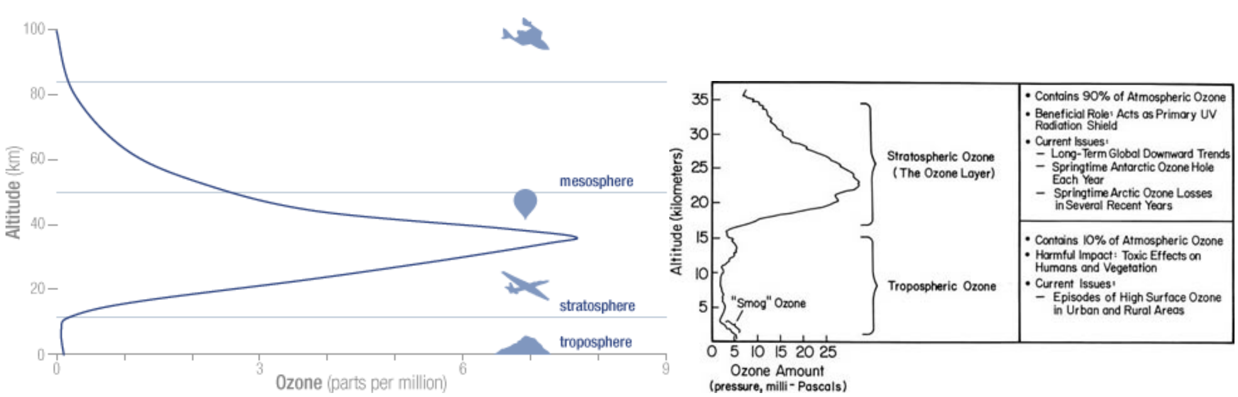


Figure 2: Left The concentration of ozone varies with altitude. Peak concentrations, an average of 8 molecules of ozone per million molecules in the atmosphere, occur between an altitude of 30 and 35 kilometers. **Right** Source: World Meteorological Organization, Scientific Assessment of Ozone Depletion: 1998, WMO Global Ozone Research and Monitoring Project - Report No. 44, Geneva, 1998.

Cosmic rays are another important variable in the study of atmospheric science. The observation between the relationship of altitude to high energy radiation as seen in

Figure 3 can be correlated to the formation of ozone. A comparison of the increasing effects of cosmic rays can also be performed to the amount of greenhouse gas concentration and the role it has with atmospheric temperature and radiation absorption or scattering. Professor Matthew Jones at Purdue University researches high energy physics and has proposed utilizing compact gas filled detectors being developed by collaborating universities at Fermilab. He is currently mediating communications with our SPS chapter and Fermilab.

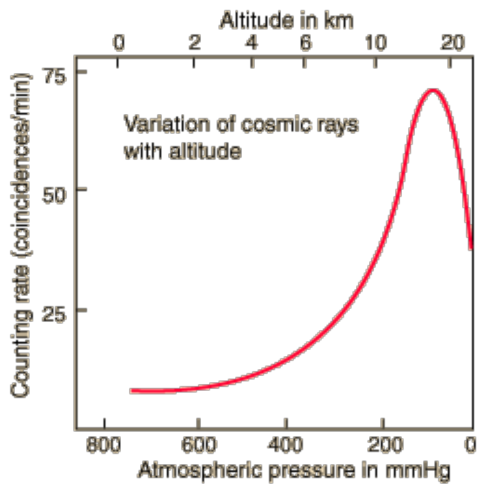


Figure 3: An illustration of a cosmic ray count as a function of altitude, first discovered by Pfotzer in 1936.

Additional experiments can be implemented in the design of the space balloon to measure for instance the amount of scattered light as a function of angle to the sun. Professor Chris Sorensen at Kansas State University is performing analytical research on how light scatters from particles such as fossil fuel soot and desert dusts that affect the Earth's radiation budget. He has agreed to advise our group with further instruction and education in the study of light scattering and help in analysing our data once collected. He also has pending a grant to use NASA's aerosol robotic network (AERONET) to study the properties of these non-spheroid aerosol particulates in the atmosphere. Measurements are currently performed by sun photometers on the Earth's surface to analyze for the spectral aerosol optical depth, precipitate water, and inversion aerosol products in diverse aerosol regimes. The spectral aerosol optical depth or optical thickness is the measurement of transparency or the amount of radiation (light) that is not reflected, scattered or absorbed. The inversion is the aberration or divergence of changes from the normal atmospheric properties as a function of altitude. Typically inversion is referred to the changes of atmospheric temperature called temperature inversions where temperature increases with height. This leads to convections and atmospheric perturbances that can be inferred by these measured inversions. Essentially by collecting data of light intensity with increasing altitude, we can compare these aforementioned variables with ones on Earth's surface and see if the measurements account correctly with what will be observed at higher altitudes.

Further contact and collaboration with faculty in the Department of Science are being established. We plan to reach out to professors in the Department of Chemistry and Earth, Atmospheric, and Planetary Science Department (EAPS). As we do so, we are continually being referred to a growing number of interested professors and participants eager to recommend various novel experiments. Hence we propose in the budget section an aggregate price of the instruments which are necessary to perform the aforementioned experiments.

Expected Results

The concentrations of nine common air pollutants and greenhouse gases will be recorded continuously as the balloon ascends to an expected altitude of 100,000 ft. As a function of altitude, the concentration of known pollutant gasses should decrease as altitude increases according to atmospheric dispersion models. However, it is known that pollutants like carbon oxides and nitrogen oxides have an intricate relationship to the formation of ozone. Since ozone concentration is non-monotonic with respect to altitude, we expect that concentrations of carbon oxides and nitrogen oxides will behave similarly. The peak ozone concentration in the atmosphere is reached at roughly 115,000 ft., after a steep concentration gradient that begins growth substantially from around 10,000 ft. This range of altitudes is the ideal range for measurements in which the fluctuations will have the highest significance. We expect to see the characteristic spike in ozone concentration as well as an associated trend in concentration of carbon and nitrogen oxides. Furthermore, we expect to see trends in other gasses associated with ozone formation such as nitrogen oxides as well as unassociated greenhouse gases and pollutants like sulfur dioxide, methane, and gaseous hydrocarbons.

Description of Proposed Research - Methods, Design, and Procedures

The Roswell III High Altitude Balloon Experiment is designed around the idea of an inexpensive and reusable atmospheric probe which should be accessible to educators and students, alike, for the monitoring of local atmospheric quality. As part of the experimental procedure of probing the concentration of nine greenhouse gases, and air-pollutants, Roswell III will look for characteristic altitude profiles and aim to identify common trends within the studied species. In order to obtain data on the concentrations of gases, the Roswell III is equipped with two onboard systems devoted to data acquisition and GPS monitoring.

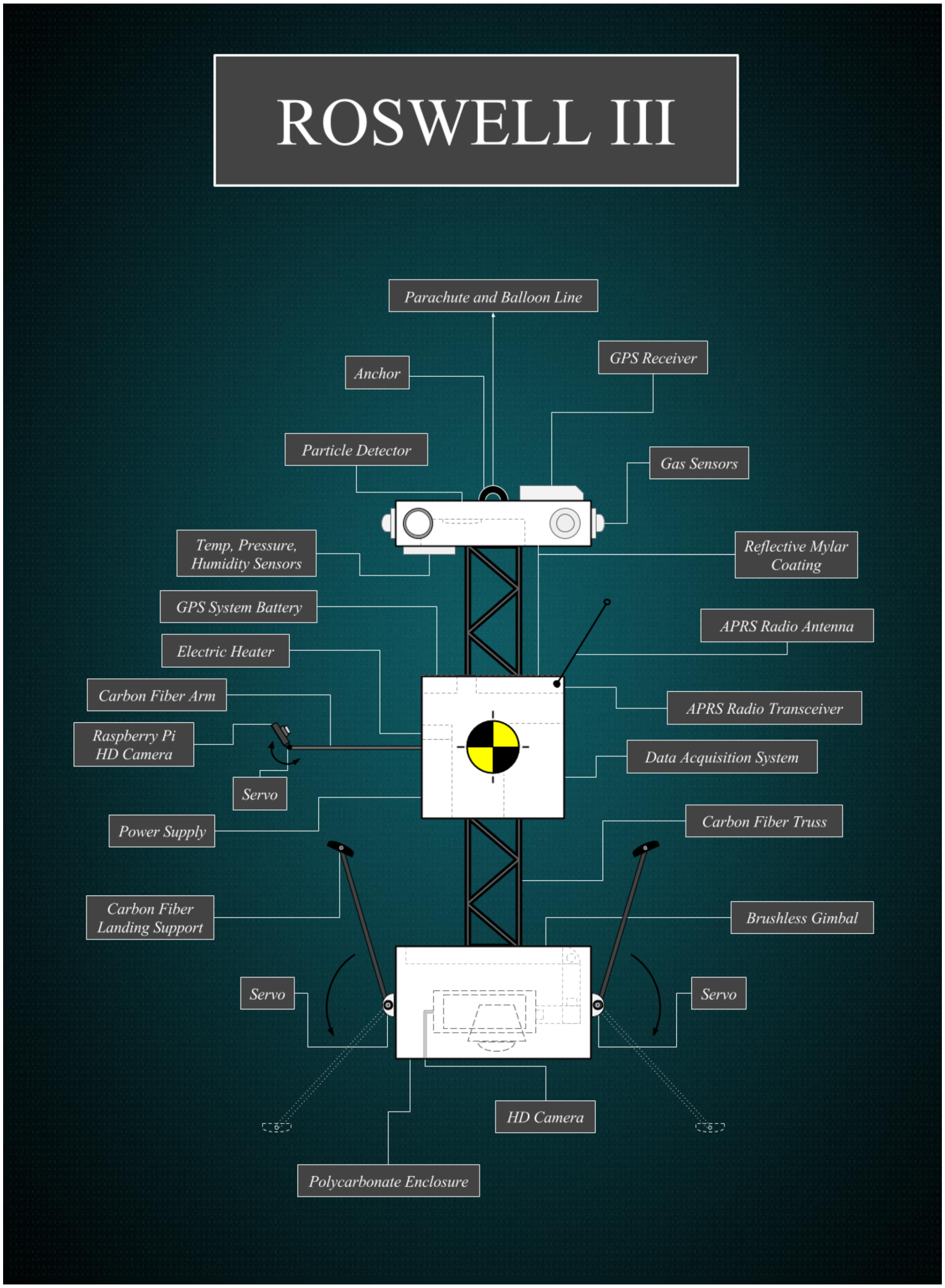
1. Payload Design

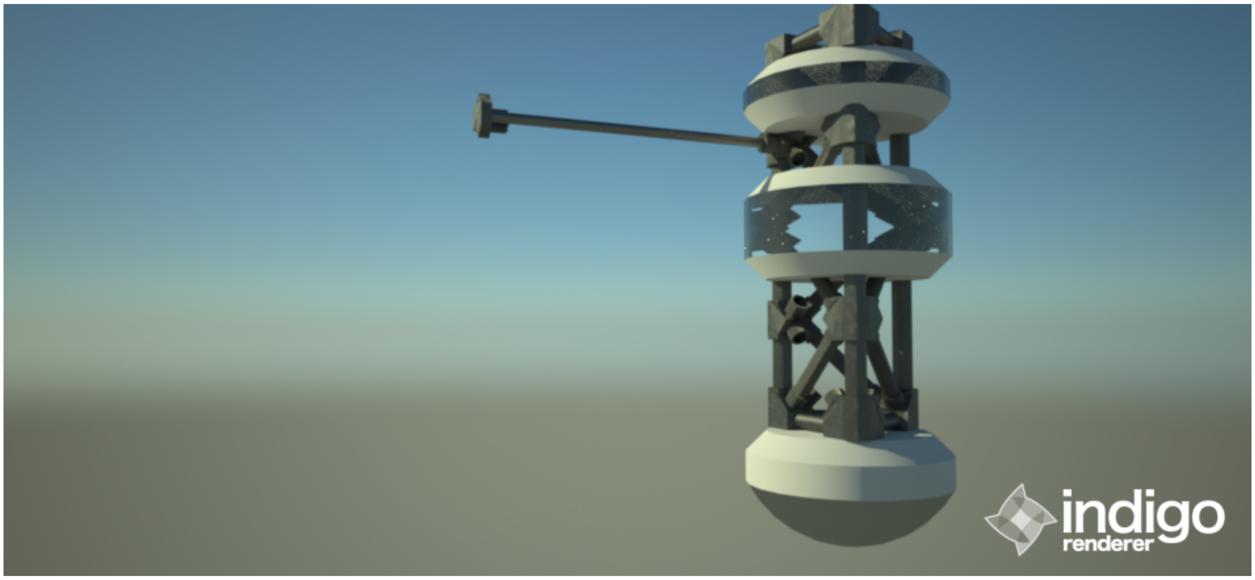
The payload will be primarily comprised of three compartments, each connected by sturdy carbon fiber trusses. The top two compartments will be made out of either high density foam or ABS plastic and will be covered with reflective Mylar wrapping to protect the sensitive components from unwanted external radiation. The insulative properties of Mylar will also help to address the internal temperature needs of several components on board. The bottom compartment will be composed of polycarbonate, and will house a 16 megapixel digital camera mounted on a brushless gimbal. This apparatus will be used to take stabilized, detailed ground shots.

In and on the top compartment will be a majority of the data collecting sensors. The gas detectors will be placed externally around the perimeter, the high-energy particle detector will be placed on the inside of the compartment, the GPS receiver will be placed on the top, and the gas, temperature, and humidity sensors will be placed on the underside of the compartment.

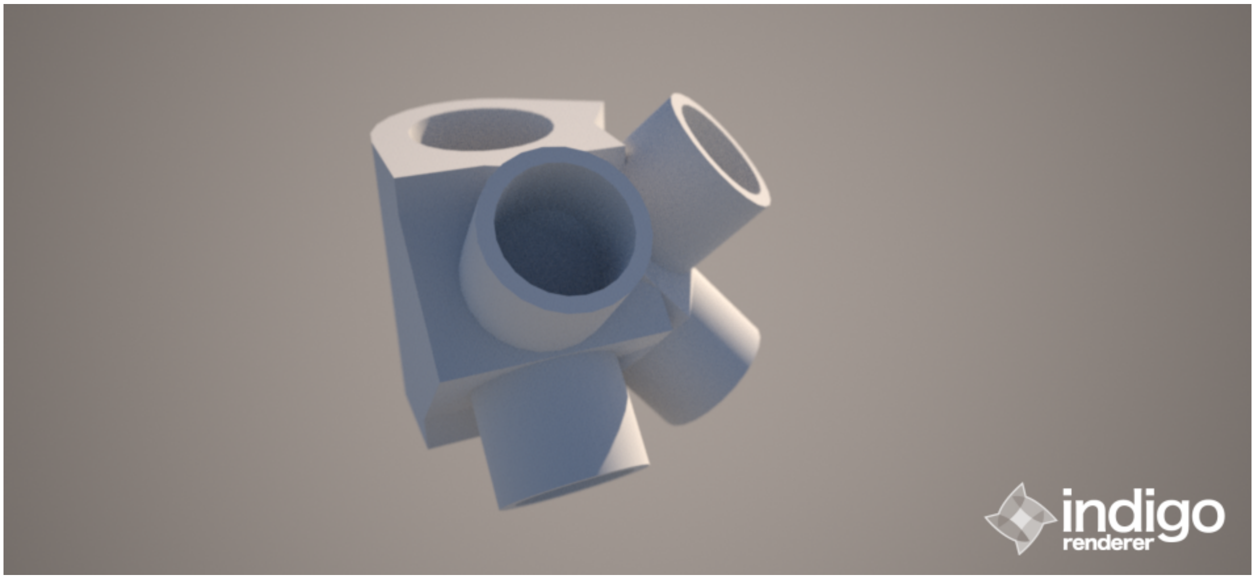
The middle compartment will house the power supplies, data storage, and heating required to keep the payload running smoothly. Attached to the compartment will be a carbon fiber arm with a servo motor and camera on the end. This will provide footage of the upper compartment, balloon, and parachute system, and will have an adjustable recording angle relative to the arm.

Facing downwards out of the bottom compartment will be a 16 megapixel digital camera mounted on a brushless gimbal, which will provide shot stability relative to the ground. Mounted on the sides of the bottom compartment will be servo motor controlled carbon fiber support legs. While in flight, the landing legs will be brought upwards, out of the view of the camera.


ROSWELL III
Parachute and Balloon Line
GPS Receiver
Anchor
Particle Detector
Gas Sensors
Temp, Pressure, Humidity Sensors
Reflective Mylar Coating
GPS System Battery
APRS Radio Antenna
Electric Heater
Carbon Fiber Arm
APRS Radio Transceiver
Raspberry Pi HD Camera
Data Acquisition System
Servo
Power Supply
Carbon Fiber Truss
Carbon Fiber Landing Support
Brushless Gimbal
Servo
Servo
HD Camera
Polycarbonate Enclosure

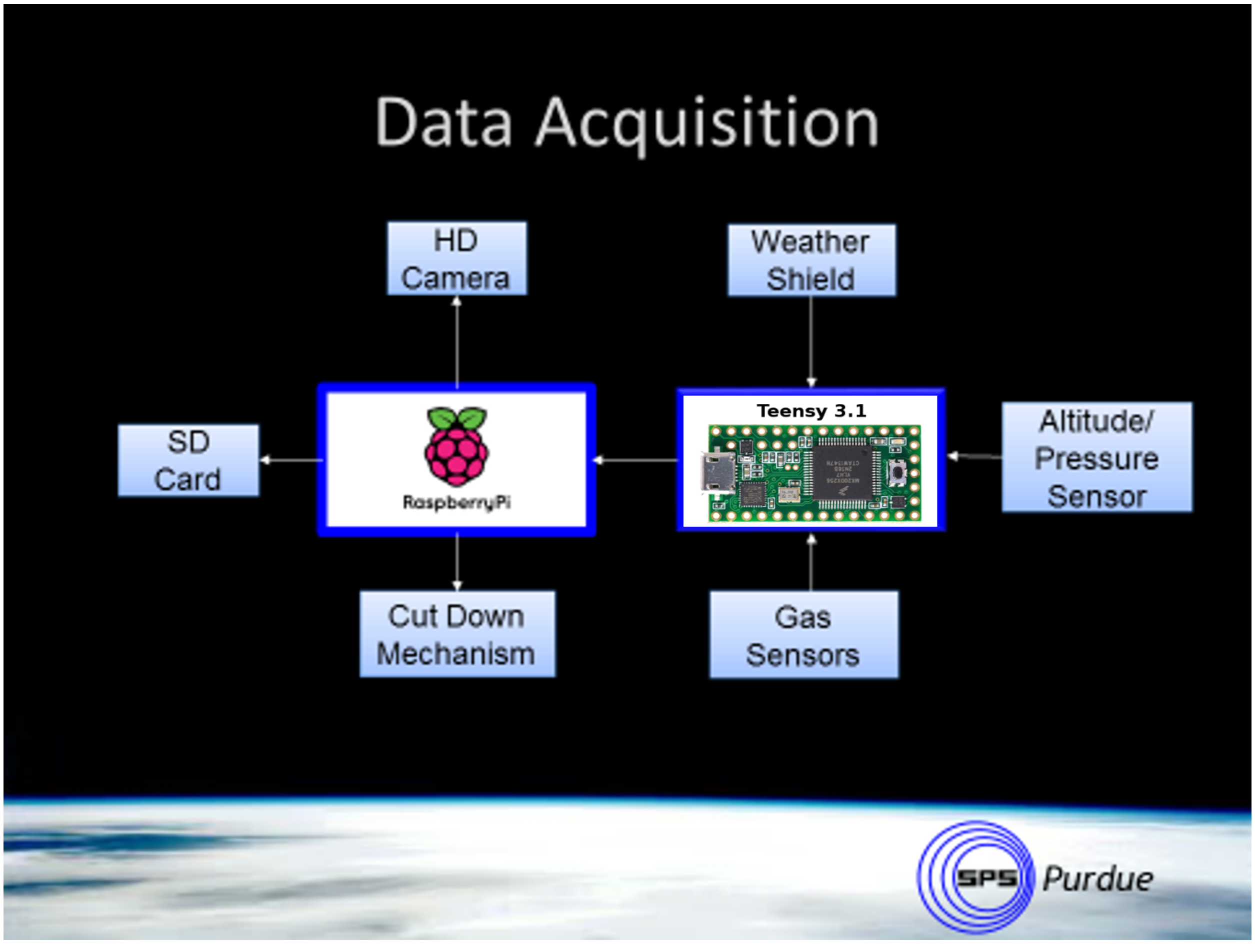


Above is a rendering of the first compartmental concept for the payload design. We expect to have cubic compartments instead of cylindrical ones for the sake of ease of construction. Furthermore, the support trusses will have a slimmer profile, about ½ as wide as shown above.



The trusses will be assembled using 3D-printed supports like the one shown above.

2. Data Acquisition

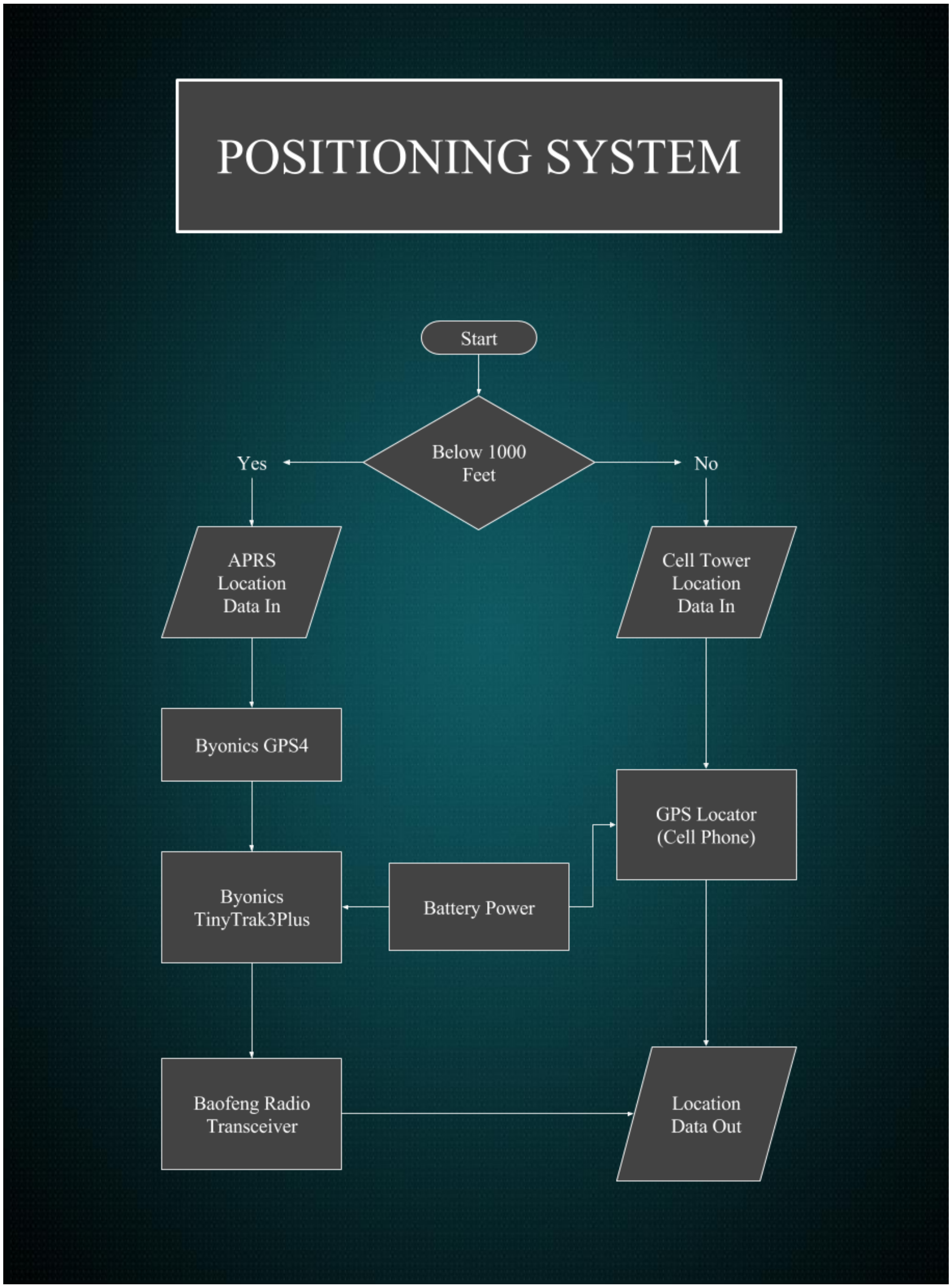


The data acquisition system is a tandem configuration of the Teensy and Raspberry Pi. The Teensy is a small sensor hub running an MK20DX256VLH7 microcontroller programmable through a C++ based language. This popular development board is capable of receiving input from analog and digital sensors and writing the data to a serial interface with the Raspberry Pi. The Raspberry Pi is a standalone processing unit running the BCM2835 CPU @ 700 MHz. This is Roswell's "brain". The Raspberry Pi will take data from the Teensy serial interface as well as photo and video information from an onboard HD camera and process it into a writable format which will be stored in solid state format continuously in order to minimize data loss in the event of a system failure. The Pi is also responsible for Roswell's cut-down and landing mechanism which will be designed to sever the connection between the craft and the balloon after 10 hours of flight time as well as deploying protective landing gear once the payload begins to lose altitude.

The data acquisition system will be taking sensor information from the following sensors:

Sensor	Analyte	Operational Threshold	Interface
HTU21D(F)	Temp, & Humidity	(-40 to 125)Deg C (20 to 80) % RH	Digital I/O
MPL3115A2	Pressure	50 to 100 kPa	I2C
ALS-PT19-315C	Ambient Light	390 to 400 nm	Analog I/O
(Ni-Cr) Thermocouple	External Temperature	-100 to 500 Deg C	Digital I/O
10K Thermistor	Internal Temperature	-40 to 125 Deg C	Analog I/O
GP2Y1010AU0F	Particulate/Dust	0-0.5 mg/m^3	Analog I/O
MQ-136	H2S (Hydrogen Sulfide)	1-200 ppm	Analog I/O
MQ-7	CO (Carbon Monoxide)	10-10000 ppm	Analog I/O
MQ-131	O3 (Ozone)	10-1000 ppm	Analog I/O
MG-811	CO2 (Carbon Dioxide)	350 - 10000 ppm	Analog I/O
MQ-6	LPG, isobutane, propane	200-10000 ppm ea.	Analog I/O
MQ-4	CH4 (Methane)	300-10000 ppm	Analog I/O
MQ-138	Hexane, Benzene, Ammonia, Alcohol	10-1000 ppm ea.	Analog I/O
MiCS-2710	NO2 (Nitrogen Dioxide)	0.2-2 ppm	Analog I/O

2. GPS System



The high altitude GPS monitoring system is run through several components. Data will be acquired by a Byonics GPS4 Receiver. This data will then be transferred to the Byonics TinyTrak3Plus GPS Position Encoder. The encoder decodes any NMEA-0183 compatible serial GPS sending $GPRMC or $GPGGA sentences.

This decoded data is sent to the FM Radio Transceiver at which point the data is sent out to be obtained by the APRS system and used to track the position of the balloon. All of these systems will be powered by a central lithium-polymer power source that is routed to each part individually.

The low altitude specific GPS provider will be a low cost, GPS-equipped cell phone or related device. The phone will have a short pre purchased plan set up in order to activate the GPS onboard. It will be powered by the central power source that was mentioned before. The data will be acquired by the GPS in the phone, sent back out to be received, and used to pinpoint the location of the balloon as it lands. This system will be initiated at the loss of signal from the high altitude GPS.

3. Camera Systems and Particle Detection

The camera systems aboard Roswell III is composed of two HD cameras. One connected to the Raspberry Pi, and another storing directly into an SD-card. The Raspberry Pi Camera is a low power component that will help to keep the power consumption at a minimum. This camera is capable of 720p video and 5MP still pictures. The Raspberry Pi camera is mounted on a servo-operated joint secured to a carbon fiber boom. This allows for 360 degree vertical view access to the payload and environment. The mounting mechanism will allow the camera to take video and picture of the horizon level as well as the balloon and payload during flight.

The second camera is a 1080p video, 16MP still Canon A2300 Powershot. This camera was chosen because of the ability to reformat it’s firmware into an open source, programmable interface (CHDK) which allows us to run an intervalometer software which controls the exposure times as well as controlling the timing of picture and video recording. The Cannon camera is mounted on a brushless gimbal housed in Roswell’s lowermost compartment. This compartment features transparent polycarbonate panels in order to assure protection and image quality.

Another A2300 Powershot is modified into a high energy particle detector. The camera’s aperture is closed and the camera shielded for low energy noise behind the compartment’s plastic and Mylar casing. Using CHDK, the camera’s sensor is “exposed” for 30 seconds every two minutes. When high energy particles, which in this case are mostly coming from cosmic rays, impact the CCD inside the camera, they leave behind white traces on the detector. Software will then be used to analyze the particle flux through the sensor as a function of altitude.

4. Balloon, Cut-Down, and Landing System

The balloon we plan to use will be a Kaymont HAB-1500 Near Space Photography Balloon, with a burst altitude between 105,000 and 115,000 feet and burst diameter of 40 ft. It will allow us to bring a 2500 gram payload to the planned 100,000 feet at a rate of approximately 285 meters/min. The balloon will end its ascent by either popping or being cut down by a nichrome wire after 10 hours. The cut down mechanism will be composed of nichrome wire, a length of paracord, and two plastic square rods. The nichrome wire will be wrapped around the paracord connecting the parachute to the balloon and connected to the Raspberry Pi for control. Then the trailing nichrome cords will be mechanically locked between the two plastic rods wrapped with the paracord to ensure tension between the parachute cord and nichrome wire. Upon running a current through the wire with the Raspberry Pi, the paracord will be cut and the balloon released. Once this has occurred, the parachute will slow its descent. The parachute itself is a square meter in size and composed of nylon. When the computer detects that the payload has descended 1000 feet, three servo motors will turn on, lowering a set of ten inch carbon fiber landing supports. These spokes will protect the internals, especially the HD camera on the bottom, from excessive trauma upon impact with the earth.

7. Flight Simulation

http://habhub.org/calc/: Rate of Assention calculation:
According to the Kaymont website, the 1500g balloon has a typical rate of ascension of 4.5 to 5 m/s when filled to 3707-4126g of neck-lift. The predicted weight of the payload is 2500g. When these figures are factored into the above burst calculator, the expected bust altitude is 106,627 - 104,170 ft respectively for the set neck-lift. Trivially, the neck-lift will be measured the day of launch using a force gauge.

http://predict.habhub.org/: Flight simulations will be done using weather forecasting data for the week of the launch.

8. Personnel & Contributions

SPS purdue members involved:

- Rafael Lang, Faculty Sponsor
- Carlos Blanco, President
- Patrick Kelley, Vice President

- Shaun Owens, Treasurer
- Adam Kline, Member
- Charles Li, Member
- Daryl Masson, Member
- Michael Yannell, Member
- Timothy Bishop, Member

Hypersight Mentors

- Chris Chance
- Shyam Thota

Project Timeline

Milestone	Date
Finalize design for 3D printing	12/15/2014
Start building Payload	01/12/2015
Finish building Payload	02/28/2015
Finalize temperature tests on electronics	03/15/2015
Finalize code for all electronic Systems	03/15/2015
Finish ALL preparations	04/05/2015
Launch	04/10-27/2015
Finish Flight Report & data analysis for GSBC & Submit	05/08/2015
Submit Report to SPS	05/31/2015

Because of the scope of the GSBC, the final report to be submitted to SPS will be the one submitted to GSBC. This report will detail the experiments carried out, designs, data, and results. This is the final deliverable.

Budget Justification

Since our first successful launch, focus is on developing a more efficient design. Our first effort was to produce a functioning space balloon. Now, after retrieving the balloon and analysing the data and flight, we are revisiting the drawing board with the assistance of experienced engineers from Hypersight Imaging. Listed first on the Budget Proposal is three Kaymont HAP-1500 balloons running at $135 apiece. 100 cubic feet of helium will be needed per balloon. These will provide us three launches.

A necessary addition to the data processing center will be the Raspberry Pi A+ CPU. Last year, a serious fundamental limitation was the voracious energy appetite of our electronics. Our current processor is too power hungry, and because of the multitude of gas sensors, added camera, and multiple servos, we will need to conserve as much power as possible.

To measure certain atmospheric gases, we have found rather inexpensive sensors ranging from $5 to $50 apiece with accuracies of down to 10 parts per million. We have chosen nine gases and scouted their respective sensors to focus on their atmospheric concentrations.

Along with the added sensors, a practical solution for the increased need for analog and digital pins for all the sensor inputs is a Teensy 3.1 microprocessor. The added pin inputs on a small single motherboard inexpensively resolves the issue of linking a multitude of new sensors with limited weight constraints.

Other than gas abundance measurements, photography and video are primary interests in our endeavour. Unlike our initial balloon model with one camera attached stationary to the frame subject to the motion of the balloon, we plan to attach the primary camera to a gyroscopic brushless gimbal that will be able to take a 180 degree aerial photography as well as video. Hypersight has already assured us a brushless gimbal. The gimbal runs at around $100 and can be equipped with a custom mount to to fit the A2300 Powershot. This camera will guarantee astounding, professional quality videos.

The Raspberry Pi camera module will be attached via servo motor to a carbon fiber boom, which is further attached to the central capsule. With 360 degrees of freedom in the payload-boom plane, the images that this apparatus captures will encompass the weather balloon and a view of space as well as the horizon and surface of the earth. A panorama can be made from these photos to capture the entire space balloon in flight. It will make for a visually striking effect.

To accommodate all these alterations, a new balloon capsule is required. Hypersight is providing access to their facilities to design the material composite of the capsule that will insulate and protect the instruments and electronics from the harsh conditions of high altitudes. The capsule materials will primarily consist of Mylar, carbon rods, ABS plastic, and acrylic plastic.

Besides the raw materials to create the capsule shell, wiring will be important to ensure better electronic connections. Our chapter lacked the proper electronic devices such as soldering irons, power supplies, breadboards, insulated wires, among other components which resulted in a prolonged first launch due to a malfunction that was resolved after having to pull out all the electronic devices and wires. Hence the request for the disclosed amount to account for random electronic and hardware components that may be needed.

Another design we plan to implement is temperature control inside the capsule housing the electronics and power source. Currently we utilize a usb battery pack for a Raspberry Pi with 10,000 mAh providing 5V at 2A. The battery operates optimally at a temperature range well above the expected ambient temperatures, hence the need for an artificial heat source. Previously we used hand warmers which unexpectedly provided excessive heat causing a buildup of humidity that may have ultimately impaired the sensor readings from the weather shield. Using thermistors, the Raspberry Pi can self regulate the temperature using a resistive heater to remain at a constant temperature.

With our current capsule concept, we are attaching the primary camera to the bottom in order to capture a completely unperturbed view of earth’s surface. During the ascension, the camera will simply be protected by a dome of transparent polycarbonate. We plan to design a landing mechanism that will deploy the landing gear after the payload has been in freefall for 1000 feet. Three servos will bring the carbon fiber legs into landing position, ideally protecting the HD camera from the trauma it would otherwise experience during landing. If the landing mechanism works as planned, we will find the craft standing upright on its 4 legs.

Another improvement to the space balloon is the recovery time which is dependent on proper design of all components.

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*datasheets found in budget proposal