2013 HASP Proposal

SCARLET HAWK - I

Abstract:

"SCARLET HAWK – I", the proposed HASP payload to be built by IIT's AIAA student chapter, is a test platform for development of future CubeSat-type missions. The payload subsystems are comprised of an onboard computer, power management, sensor packages including GPS and image capturing, and communications. The 2013 mission includes two scientific experiments investigating GPS tropospheric error and measuring stratospheric methane concentrations.

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INTRODUCTION

The student chapter of the American Institute of Aerospace and Aeronautics at IIT created its high altitude ballooning team early in 2012. The team began with very little experience building high altitude payload and few resources. In the year since then, the dedicated team members have spent on average about 10-20 hours a week, developing skills in areas often outside of their disciplines and making tremendous progress. IIT's first balloon payload, which was launched last spring, included a simple sensor package and a data logging computer. The second, which will be launched in January, includes a full communications package capable of sending GPS coordinates, sensor outputs and receiving simple commands from a distance of up to 40 miles from the chase car.

IIT's proposed payload will be a continuation of past successes in developing remote sensing and communications payloads capable of surviving near-space conditions. SCARLET HAWK - 1 will also serve as a testbed for the development of more refined autonomous, multi-mission payloads with future CubeSat missions on the horizon. The proposed payload includes two separate experimental setups and an image capturing package, which will demonstrate the ability to take and transmit images with limited downtime, even with severe bandwidth limitations.

PAYLOAD DESCRIPTION

Experiment:

Validation of Tropospheric Error Model for Global Positioning Systems (GPS)

Measurements taken by GPS receivers are subject to multiple errors that result from signal delays and distortions due to the Ionosphere, Troposphere and Multipath, receiver and satellite clock errors, inaccurate ephemeris data, and an inadequate number of visible satellites. Algorithms to estimate position fixes from GPS measurements are designed to mitigate the effect of these errors by correcting for them (in the case of clock and ephemeris errors) or by modeling them (in the case of Tropospheric and Ionospheric errors). The models, however, are generalized from assumptions and extrapolations for the index of refraction and do not provide the level of accuracy required for certain experiments. The Tropospheric error model depends on variables that can change drastically depending on the day and time of measurement. The purpose of this experiment, therefore, is to validate the existing Tropospheric error model by measuring the index of refraction as a function of altitude in real time and comparing resulting delays due to this refraction to the delays predicted by the existing models such as the Hopfield Model *(Hopfield 1969, 1971, 1972)*.

Tropospheric delay occurs in the region of the earth’s atmosphere between 0 km MSL and 42 km MSL, which is essentially the troposphere. The atmosphere at low altitudes causes a variation in the path of propagation of radio signals due to refraction of the signals. The effect of refraction on the propagation of radio signals is depicted in Figure 1.

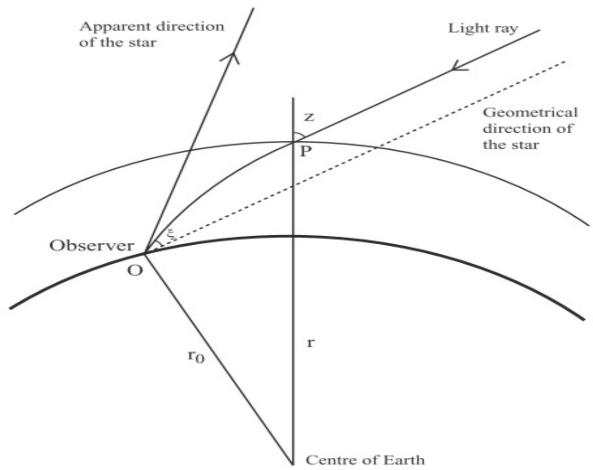


Figure 1. An example of how signals are affected by refraction (Hohenkerk, C. Y. & Sinclair, A. T. 1985)

The Tropospheric Error affecting a GPS measurement consists of two primary parts, the Wet Tropospheric (Tw) delay and the Dry Tropospheric (TD) delay. The wet tropospheric delay is the major contributing factor up to an altitude of 12 km MSL due to the existing water vapor whereas the dry tropospheric delay contributes the most at altitudes above 12 km MSL. The total Tropospheric Error (T) is calculated by adding up the two components. The experimental setup consists of three sensors measuring the atmospheric pressure, temperature and humidity against the altitude of the payload, also recorded through GPS measurements.

Tropospheric error for a radio signal traveling along the path of a 90 degree Elevation angle, an angle measured from the horizon, can be estimated by the following equation:

$$T = 10^{-6} * \int [N_D(h) + N_W(h)]dh$$

Eq. 1

where T is the total Tropospheric error (meters), NDis the dry component of the index of refraction, NWis the wet component of the index of refraction and h is the height from the receiver (meters).

The challenge is to accurately calculate the dry and wet components of the indices of refraction in order to be able to achieve an accurate result for the tropospheric error. These components can be calculated using equations derived by Rueger (2002):

$$N = 77.6890\frac{P}{T} - 6.3938\frac{P_W}{T} + 3.75463 \times 10^5 \frac{P_W}{T^2}$$

Eq. 2

where N is the total index of refraction, P is the total pressure (millibars), PWis the partial pressure of water (millibars), T is the absolute temperature (K). The partial pressure of water vapor can be calculated by using the equations derived by Buck (1981):

$$e_{sat} = (1.0007 + 3.46 \times 10^{-6} P_0) * 6.1121 * exp\left[\frac{17.502 T_0}{T_0 + 240.97}\right]$$

$$P_{w0} = e_{sat} * RH * \left[1 - (1 - RH)\frac{e_{sat}}{P_0}\right]^{-1}$$

Eq. 2, Eq. 3

where esat is the saturation vapor pressure (millibars), RH is the relative humidity, Pw0is the partial pressure of water vapor (millibars).

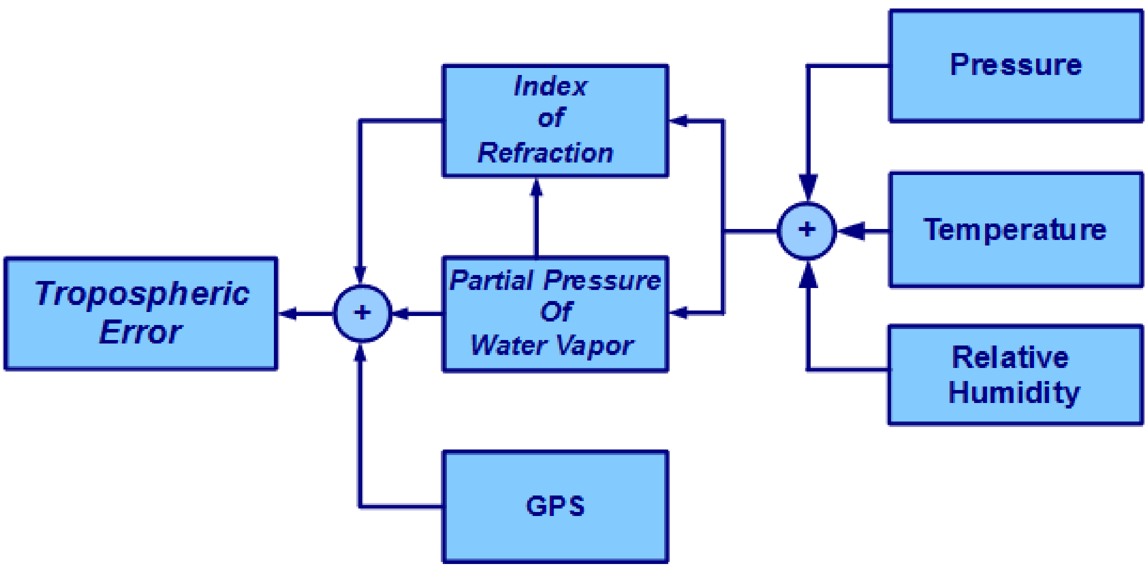


Figure 2. Block diagram showing the payload components that will be used to collect the necessary data for this experiment.

Experiment References:

1. Mangum, Jeff. "Atmospheric Refractive Signal Bending and Propagation Delay." *NRAO* (2009): n. pag. Web.

2. Milbert, D. "Sources of Errors in GPS." *GPS Explained: Error Sources*. N.p., n.d. Web. 12 Dec. 2012.

3. Stewart, Michael F. "Time and Position Data String Serial Latency Measurements." *HASP Technical Report* 2009-01 (2009): n. pag. Web.

Experiment:

Measurement of Stratospheric Methane and Water Vapor

Methane is the most common hydrocarbon trace in the atmosphere, which along with water vapor, contributes significantly to the Earth's greenhouse effect. In the last 50 years, there has been a yearly 1% increase in stratospheric water vapor. (SPARC. "Assessment of upper tropospheric and stratospheric water vapour." 2000.) Likewise, up to a 15% increase in atmospheric has been measured from 1978 to 1998 with significant variations at different altitudes. (Riese, M., et al. "Long-term Changes of Hydrogen-containing Species in the Stratosphere." 2006) In order to better predict further increases and their effect on climate, a model has been developed to predict the concentrations of methane and water vapor at different altitudes.

$$CH_4 + 2O_2 \Leftrightarrow 2H_2O + CO_2 \quad \textbf{Eq. 1}$$

The sensor package contained on SCARLET HAWK I will measure gas concentrations of methane, carbon dioxide, water vapor, as well as temperature and pressure. The relative concentration of oxygen remains nearly constant with altitude so the absolute concentration may be calculated from the pressure. In Eq. 1, the reversible stoichiometric reaction shows atmospheric methane reacts with oxygen to produce water vapor and carbon dioxide. The reaction rate is determined by the relative concentrations of the reactants and the temperature at which the reaction takes place. Eq. 2 and Eq. 3 are the governing equations where [A] is the concentration of A, the Greek letters are the number of moles produced or consumed per reaction, and reaction constants k are found using the Arrhenius equation of equilibrium.

$$k_{+.}[CH_4]^{\alpha}[O_2]^{\beta} = k_{-.}[H_2O]^{\sigma}[CO_2]^{\tau} \quad \textbf{Eq. 2}$$

$$k = Ae^{-\left(\frac{E_a}{RT}\right)^{\gamma}} \quad \textbf{Eq. 3}$$

The governing equations are then solved computationally by taking the derivative with respect to time for steady state:

$$[CH_4] = \left[\frac{\alpha k_{-.}[H_2O]^{\sigma}[CO_2]^{\tau}}{\alpha k_{+.}[O_2]^{\beta}}\right]^{\frac{1}{\alpha}} \quad \textbf{Eq. 4}$$

During the flight, Scarlet Hawk I will periodically take gas concentration, temperature, and pressure measurements to produce an altitude-based profile of gas concentrations. These measurements will then be compared with the predicted gas concentrations and, if necessary, the data will be used to develop a new predictive model.

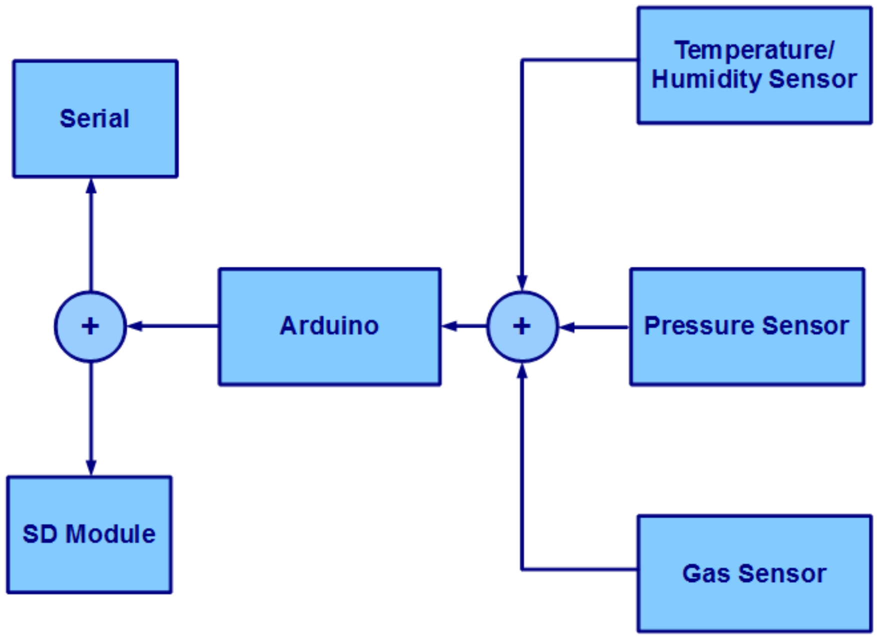


Figure 3. Block diagram showing the payload components that will be used to collect the necessary data for this experiment.

Experiment References:

1. Riese, M., J. Groos, T. Feck, and S. Rohs. "Long-term Changes of Hydrogen-containing Species in the Stratosphere." *Journal of Atmospheric and Solar-Terrestrial Physics* 68.17 (2006): 1973-979. Print.

2. Kuo, Kenneth K. "Modeling Oxidation Chain Reaction." *Principles of Combustion*. New York: Wiley, 1986. N. pag. Print.

High altitude imagery and image data transmission

Many high altitude balloon missions have included some form of photography or remote image capturing. This has typically required taking pictures that are saved to an internal memory inside the payload, and retrieved after the payload descends back to the ground. Apart from the risk of losing the payload with the data, it is also not possible to see the images until the payload is on the ground. However if the images can be converted into a data string and sent to a control station on the ground, then the information can be preserved and obtained earlier in the mission. Furthermore, for other types high altitude missions, including sounding rocket launches and CubeSat missions, real-time image transmission is a mission-critical requirement.

The purpose of the ICS (Image Capture System) is to optimize the process of image capturing and transmission from a high-altitude payload such as a HAB payload or even a CubeSat to a ground station. This will allow the ICS to stay within the narrow operating envelope defined by Baud rates, power consumption, and downtime limitations. This is achieved by powering down all other non-critical components, then using three cameras to capture images individually and transmit the image data using the HASP serial port.

The ICS comprises an Arduino micro-controller, cameras, level shifters and SD card shield. The system will use the following procedure:

- Once the GPS detects the payload has reached the expected peak altitude of 120kft, the onboard Arduino microcontroller will shut down the other sensing packages and instruct one of the cameras to take a picture.
- This picture will be received by Arduino and saved to the SD card, in JPEG format.
- The process is repeated with the remaining 2 cameras.
- When all four images have been saved, the Arduino will send the data from each picture to the HASP, which will transfer the data at a rate of 1200 baud.

Each image file size will be 3kB and at a rate of 1200b/s, the expected downtime to transmit the three images will be approximately one minute.

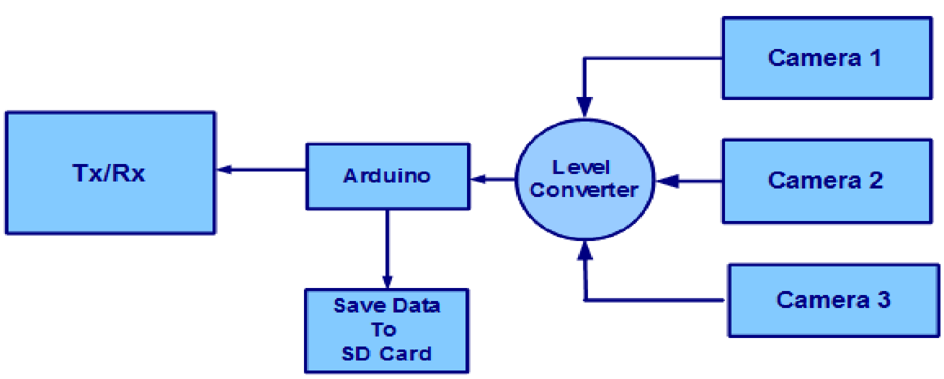


Figure 4. Block diagram showing the payload components that will be used to capture, store, and transmit the images.

STRUCTURE

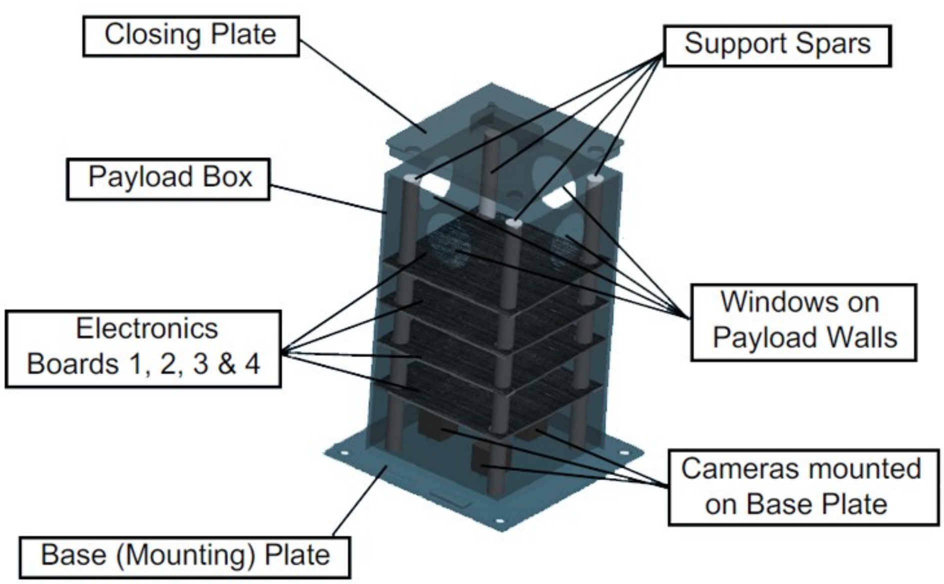
The payload structure will serve to hold the different electronic subsystems, secure the payload to the HASP structure using the given mounting plate, and will be required to survive a 10g/5g shock in the vertical/lateral direction, respectively. The SCARLET HAWK- 1 structure will make use of carbon fiber construction and a stack-able configuration with internal supports to anchor the internal components. As the following preliminary structural drawings show, four rods will extend down from the lid and will hold the four circuit boards. The ends of the rods will then be fastened to the HASP mounting plate securing the payload core inside the carbon fiber walls, which will also be secured directly to the HASP mounting plate.

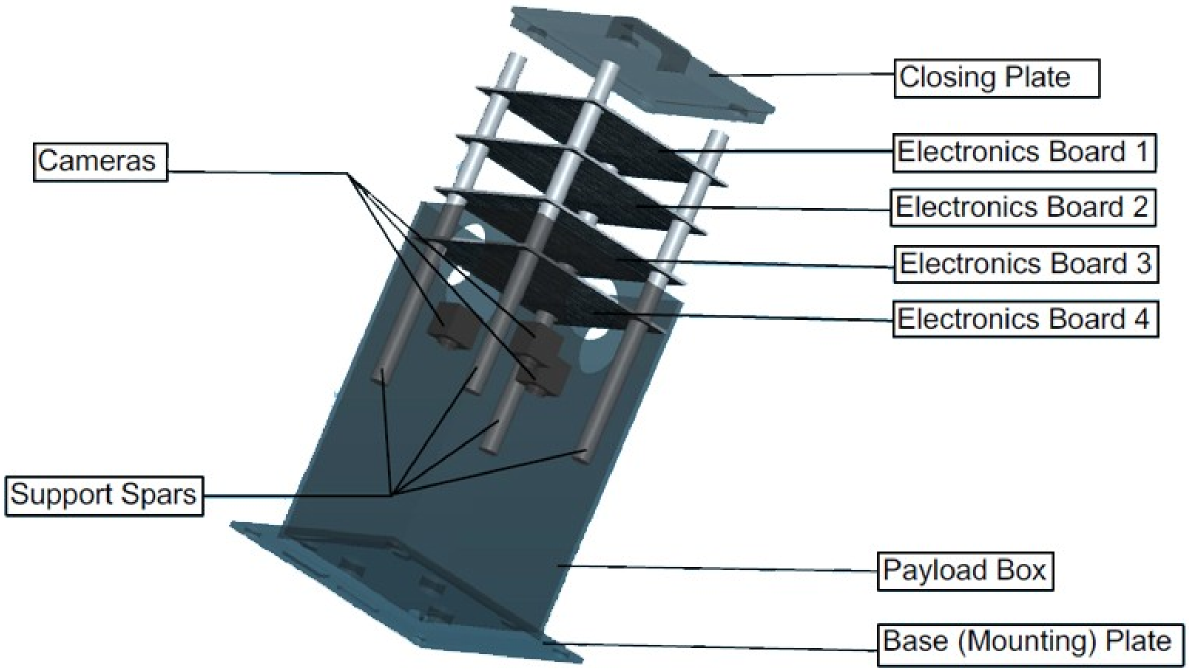
Due to the fact that the sensor board will need exposure to the outside environment, while also protecting the sensors from direct exposure to the sun, holes will be cut near the top of the payload walls. Therefore, a lateral partition will likely be included to separate the sensor board and the outside environment from the core electronics, though this design has not yet been finalized. The cameras will be secured on the underside of a lateral partition in the lower half of the payload with view holes drilled either into the bottom or the outer walls.

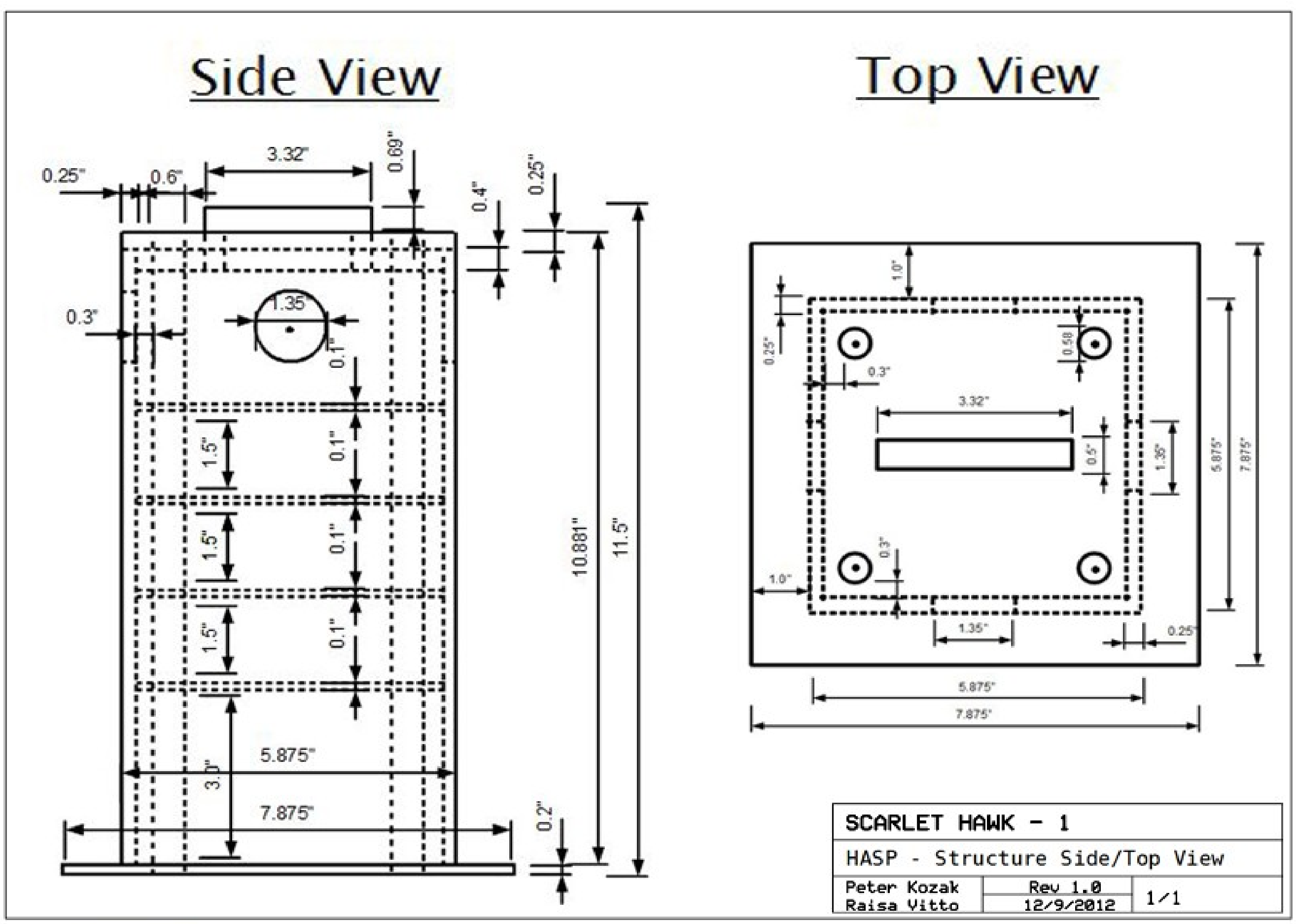
Mission Requirements:

Item	Value
Vertical Shock	10g
Horizontal Shock	5g
Footprint	15x15 cm
Height	30 cm

Preliminary Design Drawings




Closing Plate
Cameras
Electronics Board 1
Electronics Board 2
Electronics Board 3
Electronics Board 4
Support Spars
Payload Box
Base (Mounting) Plate


Side View
Top View
3.32"
0.25"
0.6"
0.69"
0.4"
0.25"
0.3"
1.35"
0.1"
1.5"
0.1"
1.5"
0.1"
1.5"
0.1"
10.881"
11.5"
3.0"
5.875"
7.875"
0.2"
1.0"
0.25"
0.58
0.3"
3.32"
0.5"
1.35"
5.875"
7.875"
0.3"
1.0"
1.35"
0.25"
5.875"
7.875"
SCARLET HAWK - 1
HASP - Structure Side/Top View
Peter Kozak
Raisa Vitto
Rev 1.0
12/9/2012
1/1

ELECTRICAL SUBSYSTEMS AND POWER BUDGET

The payload electronics will be comprised of four printed circuit boards, containing the on board computer, power management system, image capture system, and sensing circuits. At different times throughout the mission, the payload will run on one of two different modes of operation: Sensor Mode or Camera Mode.

Two Arduino Mega microcomputers will make up the on board computer with the ability of the first microcomputer contained on circuit board 1 to turn on or off the second one on circuit board 4. By splitting the electronics into two subsystems, it will allow SCARLET HAWK - 1 the flexibility to perform several different missions while minimizing the resources needed to function. The main challenge for keeping within the HASP power requirements, is the power budget is the maximum current limitation. Power use will actually be quite low, well below the 15W specified.

In the two power budgets below, the voltage and maximum current data were collected for those components that will be connected to power during that given mode of operation. It is unlikely that all of the components will be running at their maximum current simultaneously, but even in this rare event, neither the current or power limits were exceeded.

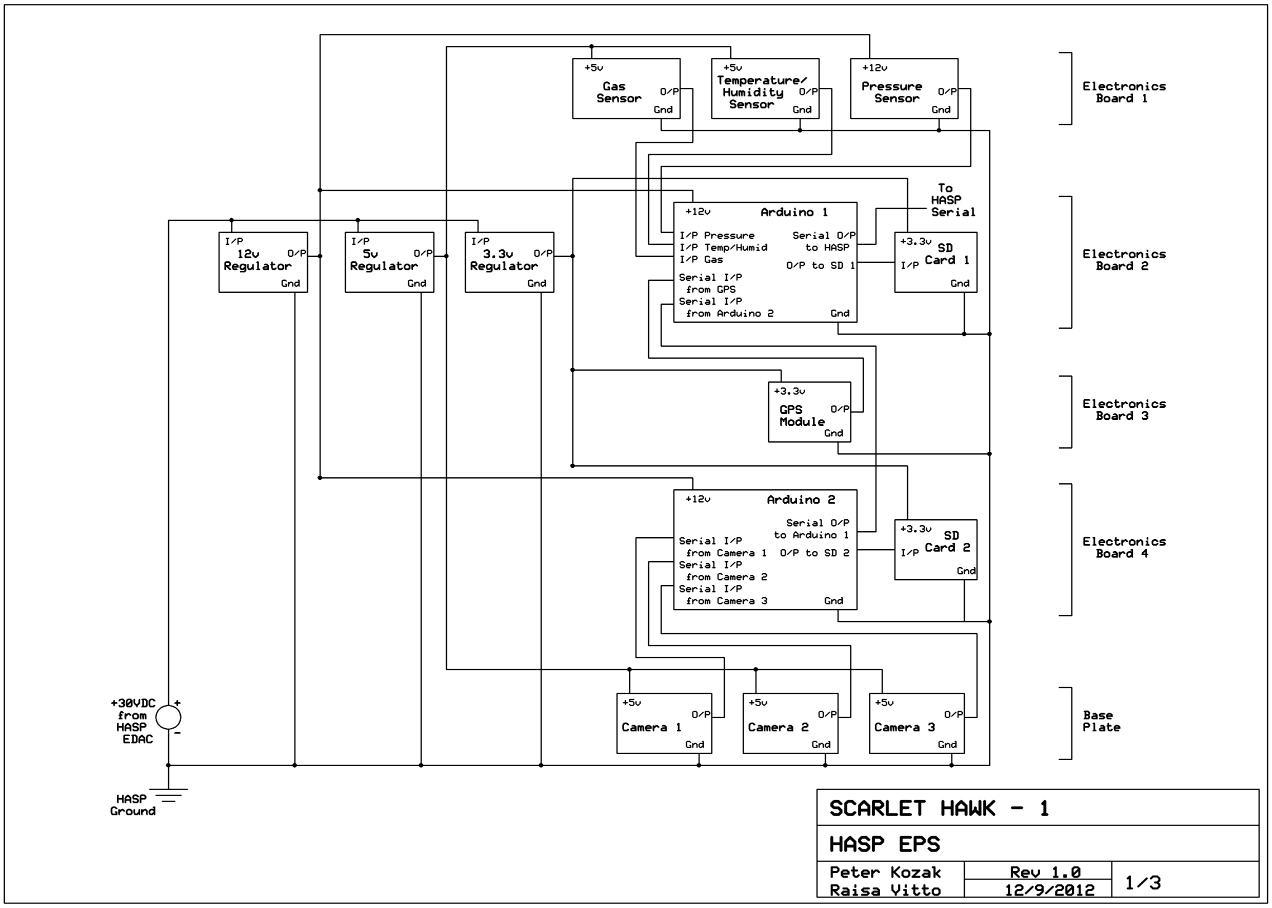
Sensor Mode - Worst Case Scenario

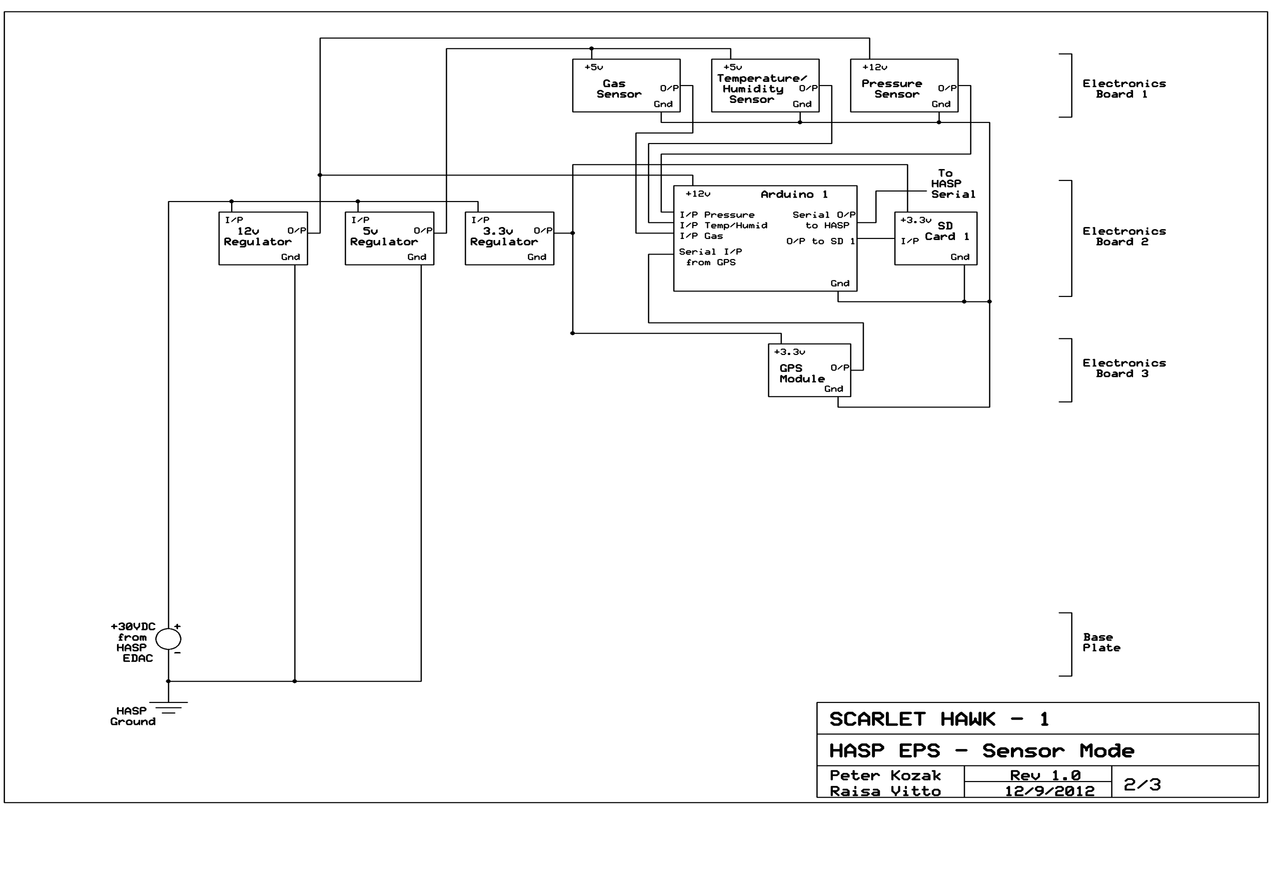
S.No.	Item	No.		Input Supply voltage	Units	Max. Current	Units	Max Power	Units
1	12 V Regulator	1		30	V	8	mA	240	mW
2	5 V Regulator	1		30	V	8	mA	240	mW
3	3.3 V Regulator	1		12	V	10	mA	120	mW
4	Pressure Sensor	1		12	V	2	mA	24	mW
5	Arduino Mega	1		12	V	140	mA	1680	mW
6	Humidity and Temp. Sensor	1		5	V	0.02	mA	0.08	mW
7	Methane Gas Sensor	1		5	V	45	mA	225	mW
9	GPS Module	1		3.3	V	60	mA	198	mW
10	Micro SD Breakout Boards	1		3.3	V	75	mA	247.5	mW
	Total Power					**0.35**	**A**	**2.97**	**W**
	Power Required with Additional 25% for safety					**0.44**	**A**	**3.72**	**W**

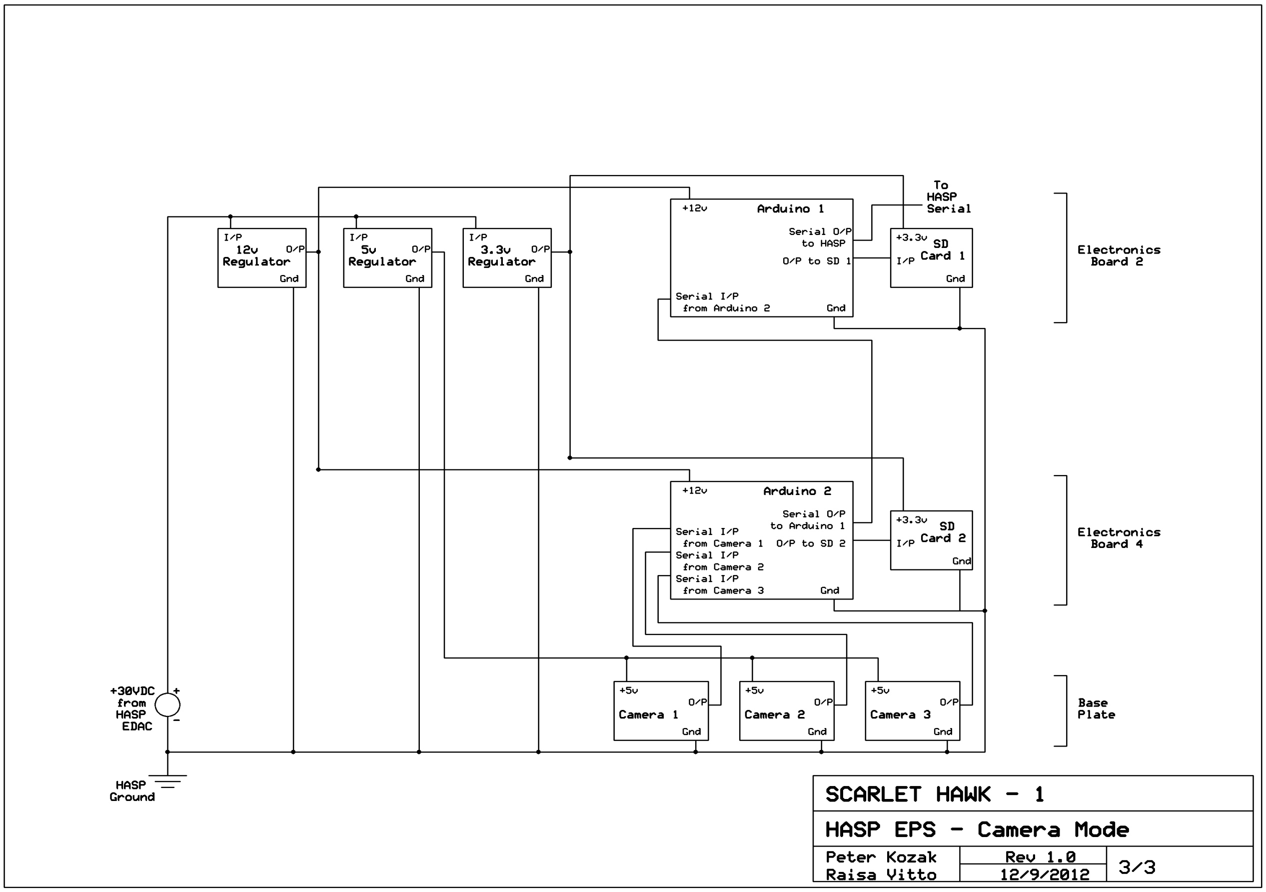
Sensor Mode - Worst Case Scenario

S.No.	Item	No.		Input Supply voltage	Units	Max. Current	Units	Max Power	Units
1	12 V Regulator	1		30	V	8	mA	240	mW
2	5 V Regulator	1		30	V	8	mA	240	mW
3	3.3 V Regulator	1		12	V	10	mA	120	mW
5	Arduino Mega	2		12	V	280	mA	3360	mW
9	Camera	1		5	V	80	mA	400	mW
10	Micro SD Breakout Boards	1		3.3	V	75	mA	247.5	mW
	Total Power					**0.46**	**A**	**4.61**	**W**
	Power Required with Additional 25% for safety					**0.5**	**A**	**5.76**	**W**

Preliminary Electrical Schematics





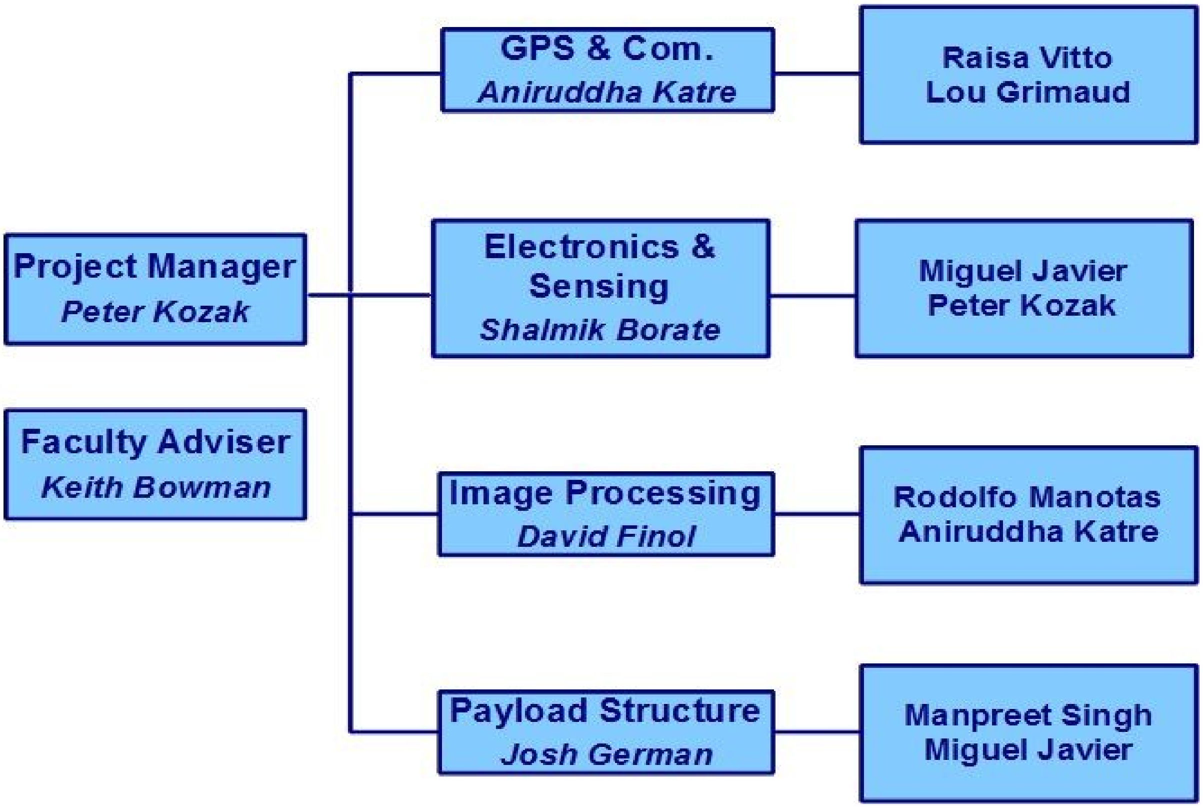


TEAM MANAGEMENT, FUNDING, AND SCHEDULE

The IIT- AIAA student chapter is run independently by students elected by the general body and disperses funds to any active projects and teams. The high altitude ballooning team is led by project manager Peter Kozak with guidance from faculty adviser Keith Bowman. The entire team is made up by six graduate and four undergraduate students. Graduate students are primarily responsible for leading the various subsections and responsible for high-level technical design and troubleshooting while the undergraduates are engaged in every aspect of design to the best of their current educational level and abilities. Almost all of students involved will still be attending IIT as of December 2013 and more members are expected to be added throughout the design process.

As of December 2013, over $9,000 has been awarded to the IIT-AIAA high altitude ballooning team since it was founded at the beginning of 2012. Funding is provided directly from the Illinois Institute of Technology through the student activities fund and additional funds are currently being solicited from local aerospace firms.

AIAA-IIT High Altitude Ballooning Team Structure



Basic Project Schedule and Deliverables

Date	Item
10/09/12	Mission Requirements and Literature Search
11/01/12	Preliminary Electrical Schematics and Breadboarding
11/27/12	Preliminary Structural Design
12/14/12	HASP 2013 Proposal Deadline
01/29/13	Structural Design Frozen
02/07/13	Subsystem Integration
03/05/13	Final PCB Design Complete and Tested
03/13/13	Structure Manufacturing Complete
04/19/13	Preliminary Payload Specification and Integration Plan
05/TBD/13	Thermal/Vac Testing in Palestine, TX
06/21/13	Final PSIP Due
07/26/13	Final Flight Operations Plan Due
07/29/13	Payload Integration