ILLINOIS INSTITUTE
OF TECHNOLOGY

2016 HASP Proposal:
Scarlet Hawk IV

Payload Title: Scarlet Hawk IV

Payload Class: Small	**Institution:** Illinois Institute of Technology	**Submit Date:** 12/18/2015

Project Abstract:

Every year, the HASP program offers an opportunity for students to design, build and test a payload for stratospheric balloon flight. After a successful mission at end-of-summer 2015, IIT's AIAA chapter is submitting a new application for the 2016 mission. Our proposal includes a main engineering experiment: a communication system between our payload and a ground-station. Learning from last year's mission, we also designed a new version of the same structure. Adding some elements into the structure, we came up with a more robust and reliable frame.

Furthermore, we chose to implement a compartment to both secure locate all electronics boards but also allow an easy access to any of their components (in case a replacement is needed). We hope to have found a structure to be used in our future missions. With the implementation of this new structural design and an autonomous communication, we hope to get closer to a CubeSat mission—our long-term goal.

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Outline

Introduction

IlT's Ballooning Team is formally part of the local student chapter of the American Institute of Aeronautics and Astronautics (AIAA). AIAA-IIT's executive board is democratically elected by the student body and allocates funds to student-managed groups for engineering projects. This chapter's support has allowed IIT'S Ballooning Team to complete three full payloads. These efforts began in 2012 with only a couple students, both of whom had very little ballooning experience. Two years of work yielded the Scarlet Hawk I, a small payload that flew in HASP 2013.

After that successful mission, our chapter decided to look toward bigger goals. Not only did we further develop the high-altitude ballooning program on campus, but we began work on CubeSats for the near future. This lead to the building of Scarlet Hawk II, which mixed our past experiences in ballooning with our future plans for a CubeSat program. This small payload implemented a solar powered autonomous energy system, which flew in HASP 2014. The Scarlet Hawk III was our follow-up to those projects. Our goal with the Scarlet Hawk III was to send our gathered data to the surface via a satellite communications system. The communications system proved a challenge however, and this challenge inspired us to innovate our system for this year, thus, our goal is once again to successfully launch an operational communications system. If this system functions, we will be able to proceed with applying for a 2017 CubeSat mission.

The design of this payload involved the collaboration of students from two different departments—the Mechanical, Materials department and Aerospace Engineering department, and the department of Electrical and Computer Engineering. We seek to further the technical knowledge of our team and strengthen research and implementation abilities on future high-altitude ballooning and CubeSat missions.

General Principle of Operations

Overall System Design

As mentioned, this mission will include the implementation of a communications system, based in satellite communications, able to connect to our ground station (located in the launching point) throughout the whole flight. Furthermore, the system will be testing the performance of various frequencies and modulations, the best combination of which will be chosen at each given moment. The information transmitted will come from a collection of sensors, recording the environmental conditions of the payload—temperature, pressure, humidity, etc.). There will also be a camera taking pictures throughout the flight.

Additionally, we have implemented a control system, which will monitor and secure the integrity of the experiment. The payload will continuously control the components of the system and send necessary information through the downlink. If some failure is detected, we can correct the behavior, or shut it down completely if necessary. This control system will allow us to change the parameters of the communication system in case no connection can be established.

In the following figure, we see the connection block diagram of our system. It presents a receiver/transmitter configuration, where the payload acts as a passive receiver. That said, both the payload and the ground station will be configured so that each may act as receiver and transmitter.

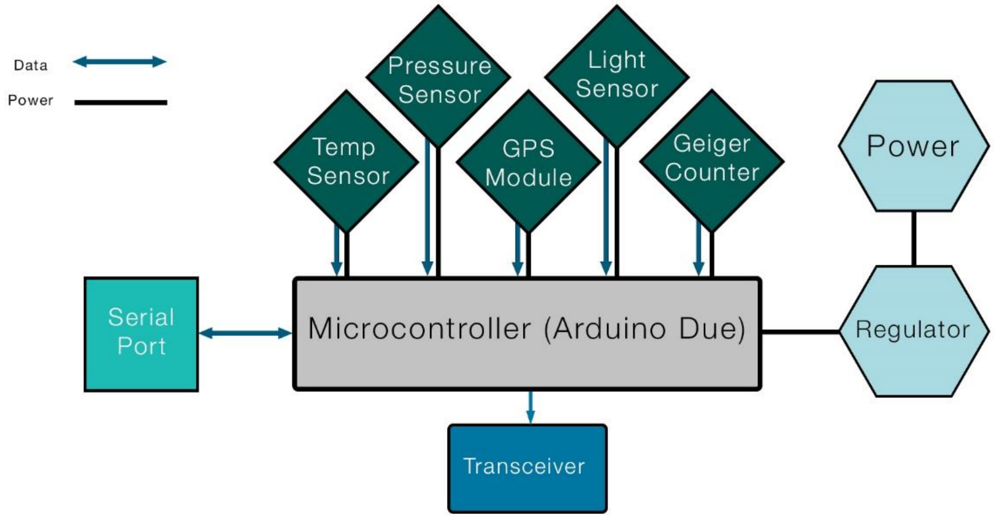


Figure 1. Connections block diagram

Objectives

- Test performance of modulations commonly used in CubeSat missions.
- Check results when using other modulations.
- Measure antenna radiation pattern and gain and compare them with the theoretical values.
- Autonomously monitor the performance of the power consumption and behavior of every critical component of the system. Be able to shut down any malfunctioning device which might compromise the results of the whole mission.
- Monitor the environmental conditions of our payload (temperature, pressure and humidity values).

Technical Experiment: Communication System

1. Description of the system

IIT will once again implement its own communication system in the HASP 2016 venture. The purpose of this experimental subsystem is to test a communication link between IIT's payload, but it also reaches to a higher objective: a future autonomous CubeSat mission. The communication system is one of the essential parts in any satellite mission, its main objective to provide data exchange between the satellite and ground station, all this with minimum reliability on the NASA system. In this mission, we seek to draw from last year's successes and improve on the failures.

Last year, our antenna design successfully improved the gain on our signals, however, no control of the frequency, nor modulation was achieved. In this experiment we would like to use varied frequencies and communication channel configurations. We will obtain assorted data from the performance of each configuration in all frequencies assigned to our project; this will help us select the configurations best suited to a future mission.

2. Principles of operation

For our modulation we chose to use GFSK, as such is the capability of our chosen transceiver. Our transceiver was selected on a basis of past successful missions carried out by other groups, and the wide range of possibilities with it. Our main objective is to check the efficiency of GFSK in this setting. The data transmitted will be twofold: telemetry read from sensors within the payload, and bit streams testing, both to provide useful information about our communication link.

Our modulation scheme decisions are rooted in simplicity; the power of the signal emitted by the antenna could be low (below 2W), and depending on height and atmosphere conditions, a dense modulation could cause high error rate. Since this experiment is a predecessor for a future CubeSat communication system, we must take into account the operational factors of that mission, such as actual height and power conditions. Apart from the modulation mentioned before, we could also use some other FSK modulation settings for the purpose of testing. We will try to use modulations with even more symbols, if the power and noise restrictions allow it.

2.1.Propagation analysis

In this section, we will approximate the receiving power, which can be used to adjust the sensibility and transmission power of our system. Generally, we want to maximize sensibility and to minimize transmission power. To obtain this received power, we need to first analyze the surrounding environment and general conditions of the flight, set an initial transmitting power and perform some basic propagation calculations.

General Conditions

Using data from prior missions, we aim to approximate the surrounding and general conditions of the payload during flight. With this analysis we will obtain the altitude, maximum horizontal distance and general location.

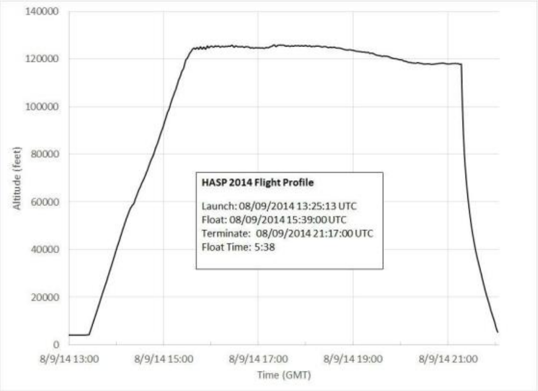


Fig. 2: HASP 2014 Flight Profile

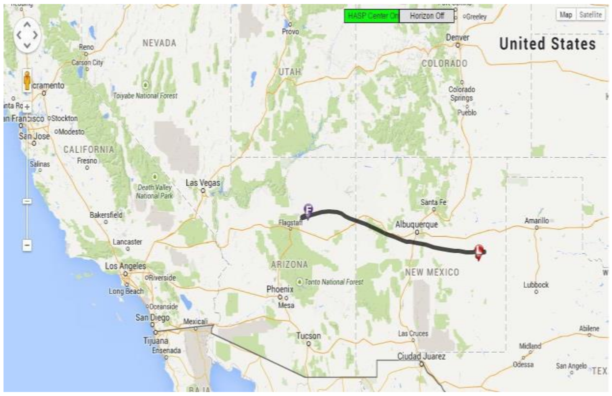


Fig. 3: HASP 2014 Flight Map

The general flying altitude, as shown in Fig. 2, is 120,000 ft (equal to 36.576 km).
From Fig. 7, we see that the regions we need to consider during the flight are New Mexico, Arizona and Colorado. We will also approximate maximum horizontal distance, as judged from mobile payload and the static ground station. This horizontal maximum distance is reached at the end of the flight. Our prior flight data indicates a the total flight distance of 465.83 miles (749.680716 km) and 520.41 miles (837.51871km) in 2014 and 2014 respectively. We will use the greater value.

Combining the flying altitude and the maximum distance, we obtain a maximum distance, which will be used in the propagation analysis

Maximum Distance= $\sqrt{FlyingAltitude^2 + HorizontalDistance^2}$ = 83.2 km

Transmitter

To characterize the transmitter antenna, we will set a transmitting frequency and power. For the frequency, we will be working in the 70cm-band (420–450 MHz). Among those values, we chose the 437MHz frequency. For power, we chose 1W.

Power balance

A Line Of Sight (LOS) is secured during the entire flight. Consequently, we will be studying the propagation of a radio signal. First, we will consider the free space Losses. Its behavior is determined by the equation:

$$L = \frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

$$L_{dB} = 10\log\frac{P_t}{P_r} = 20\log\left(\frac{4\pi d}{\lambda}\right)$$

$$= -20\log(\lambda) + 20\log(d) + 21.98\,\mathrm{dB}$$

$$= 20\log\left(\frac{4\pi f d}{c}\right) = 20\log(f) + 20\log(d) - 147.56\,\mathrm{dB}$$

Next, we will consider the gain of our communication system over highly directive antennas (this gain is represented by the receiver antenna Gain, Gr, and the transmitter antenna gain Gt). The ration Pt/Pr is now:

$$\frac{P_t}{P_r} = \frac{(4\pi)^2 (d)^2}{G_r G_t \lambda^2} = \frac{(\lambda d)^2}{A_r A_t} = \frac{(cd)^2}{f^2 A_r A_t}$$

$$L_{dB} = 20\log(\lambda) + 20\log(d) - 10\log(A_t A_r)$$

$$= -20\log(f) + 20\log(d) - 10\log(A_t A_r) + 169.54\mathrm{dB}$$

The atmospheric absorption has not been taken into consideration. It is only relevant for frequencies greater than 5GHz (not our case). Other attenuation factors not considered are the atmospheric absorption, atmospheric refraction, the terrain factors and obstacles.

As a result, we can now express the received power using Friis equations. We only need to satisfy that the distance as much greater than the wave-length. In our model, the distance is 80km, and the wavelength 70cm (80km>>70cm).

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2$$

$$P_r = P_t + G_t + G_r + 20 \log_{10} \left(\frac{\lambda}{4\pi R} \right)$$

Where:

- Pt (power delivered to the transmit antenna) = 1W
- R (distance) = $83.2*10^3$ m
- f = 437MHz
- λ =68.65 cm

As the antennas for purchase have not yet been decided upon, Gr and Gt values are still unknown. However, we have calculated the power we will have at reception in two typical cases:

In the first case, we have no antenna gain (Gt = Gr = 1). Then, the received power is Pr = -113. 71dBm = $4.25*10^{-15}$ W

In the second case, we use typical gain values (Gt = Gr = 44 dB), with a Pr = -25.7 dBm = $2.68*10^{-6}$ W

We are expecting a received power of around $2.68*10^{-6}$ W, though we will have the exact theoretical value once the antenna is implemented.

Electronic System

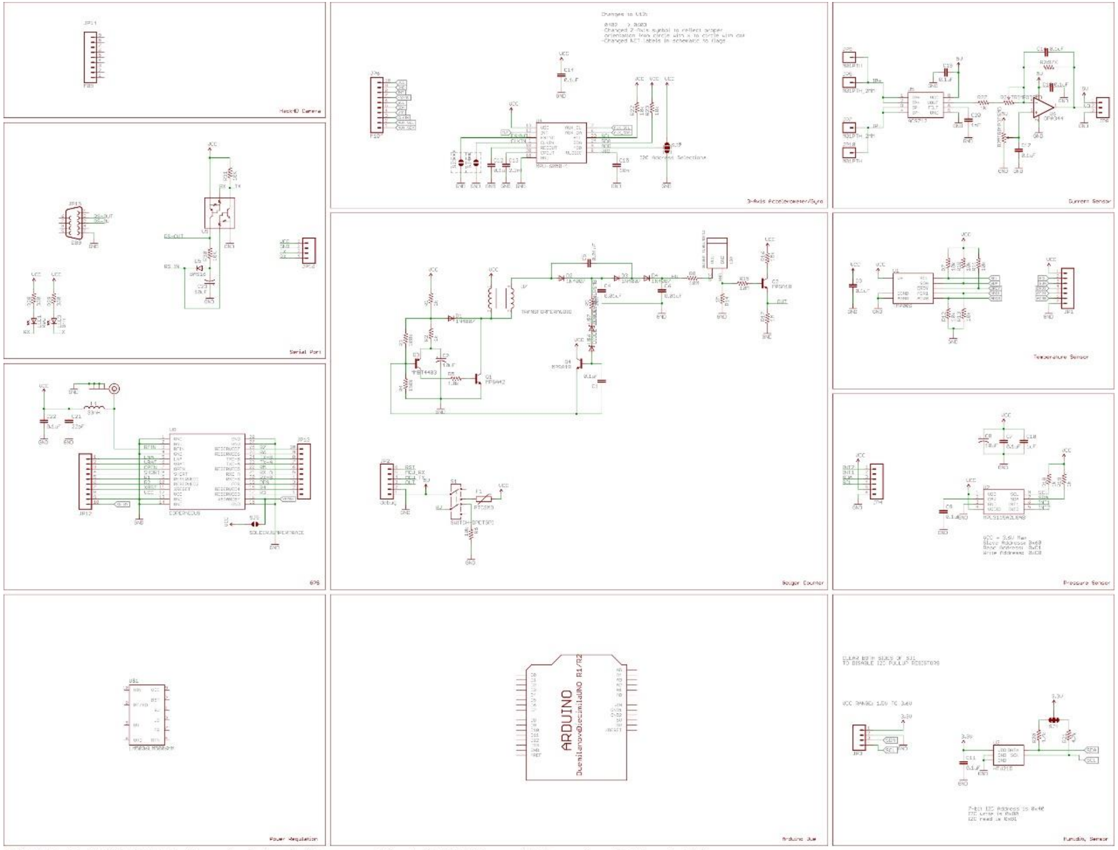
Description

As we can see in Figure 1, the Arduino Due electronic circuit will be used to manage all the sensors, as well as the data transmission experiment. The four sensors are as follows: temperature and humidity, pressure, light and radiation. Through these, we can obtain a complete analysis the payload’s surrounding environment. We will also control the temperature and the current of our circuit to avoid internal damages. Apart from the sensors, there is also a HackHD Camera, which will capture photos throughout the trip.

The power provided by NASA is converted with a synchronous switching voltage regulator that, with the addition of other components, will output 9V, 5V, and 3.3V to accommodate all sensors and equipment power requirments.

Schematics

The next figure is the schematic of the circuit, where you’ll find a representation of all connections:



12/17/15 11:12 AM f=0.47 /Users/kevinhardin/Documents/eagle/HASP/General Schematic.sch (Sheet: 1/1)

Figure 4. Electronic circuit schematic

Power Consumption

The power budgets for individual components (sensors and camera) were calculated by finding the voltage usage of each component, and thus the constant current in amperes. Using this information, we calculate the active power usage of our components.

Sensors	**Voltage**	**Current**	**Power**
Temperature & Humidity (HTU21D)	1.5-3.6 V	Sleep: 0.14 µA Supply: 0.50 mA	Min: 1.38 µW Max: 3.575 mW
Light sensor (TEMT6000)	-	-	Total: 100 mW
Pressure sensor (BMP085)	1.8-3.6 V	Low power: 3 µA High Power: 12 µA	Min: 5.4 µW Max: 43.2 µW
Arduino Due	7-12 V	0.2 mA	Min: 1.4 mW Max: 2.4 mW
Geiger Counter	5V	30 mA	Total: 150 mW
GPS Module (Copernicus II)	3.0 V	40 mA	Max: 0.12 W
Accelerometer (MPU 6050)	2.375 – 3.46 V	3.9mA	Min: 9.26 mW Max: 13.5 mW
Transceiver (Si4464)	1.8-3.6 V	R: 13.6 mA T: 85.0 mA	Min: 0.0245W Max: 0.306 W
Power Amplifier	12 V	90 mA	Total: 1.08 W
TOTAL	**-**	**-**	**Min: 1.49 W** **Max: 1.77 W**

Table 1. Overall power consumption

Structure

Description

The payload can be divided into three primary structural elements—the outer shell, the aluminum frame, and the component housing case. The outer shell will be composed of CFRP (Carbon Fiber Reinforced Plastic), a material with low thermal conductivity to minimize heat absorption under high-altitude conditions. The shell will also protect the inner components against radiation, frigid temperatures, and debris.

The metal frame for this year's structure will simply be the same as last year's, as the structure returned completely unharmed and held up very well. We will be implementing a simple drawer system to improve the

The metal frame is composed of extruded aluminum 6061 L-brackets, all attached with 2-64 screws (the welding together of last year's aluminum plates was a real struggle and we're trying to prevent similar issues). The L-brackets provide shelving for internal X-plates, which offer additional support against horizontal shock; they also subdivide the frame into three internal compartments—the top and bottom for cameras, sensors, and antenna adapters, and a middle section, where the removable housing case lives. The housing case, composed of glued ABS plastic, includes shelving for the various circuit boards.

The aluminum frame is constrained to the baseplate by small aluminum tabs spot-soldered to the frame.

Attached to the outer frame will be the two antennas of the communication system. They will be located in two adjacent faces, in the middle. Each antenna is perpendicular to its face and has a length of 17cm (exceeding the maximum dimensions of a small payload). Both the side and the orientation are required in order to guarantee a correct communication payload-ground: the 17 cm are given by the frequency range whereas the orientation generates the optimal propagation diagram.

For clarity of the model, a simplified version is used in the following representations (not including the antennas, for instance).

Preliminary Design Drawings

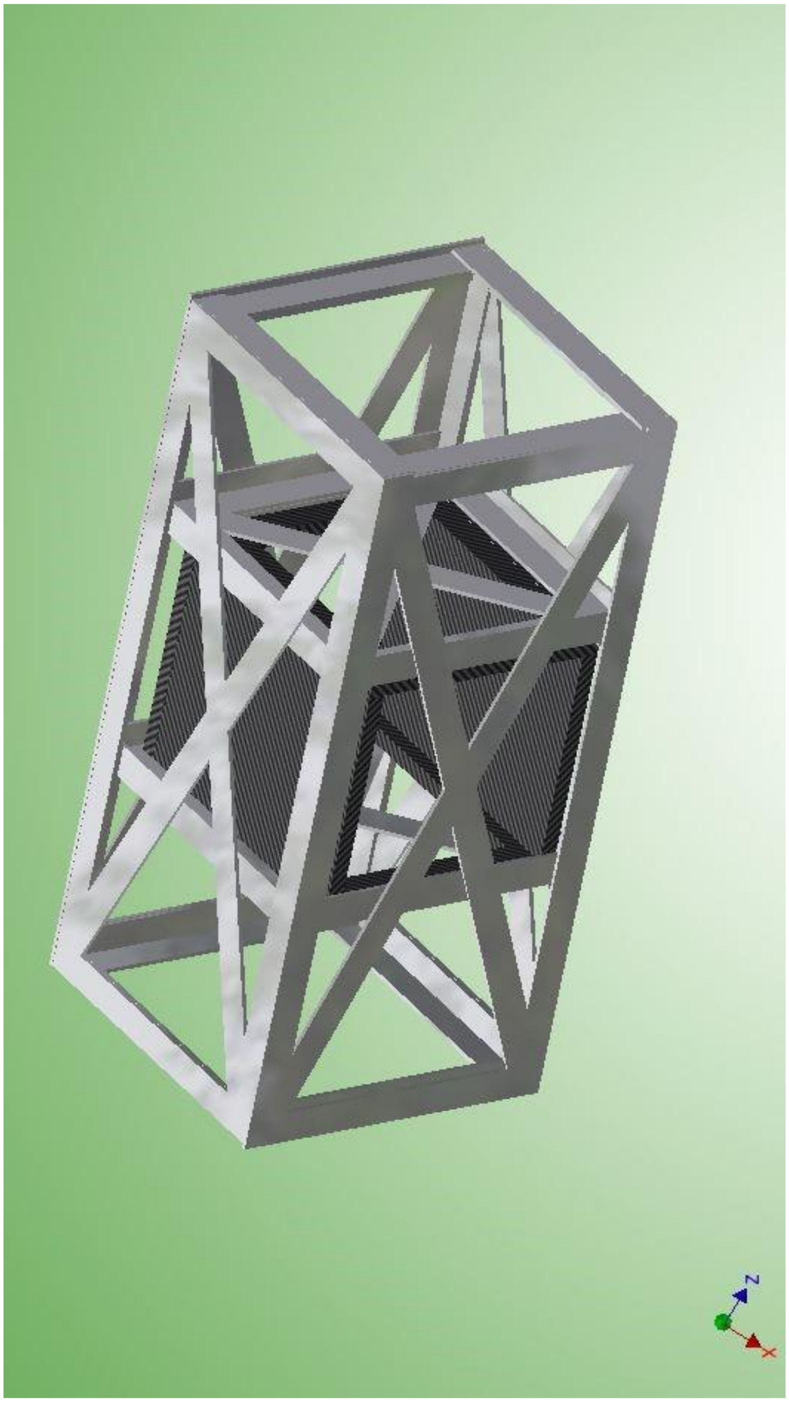


Figure 5. Frame, full view

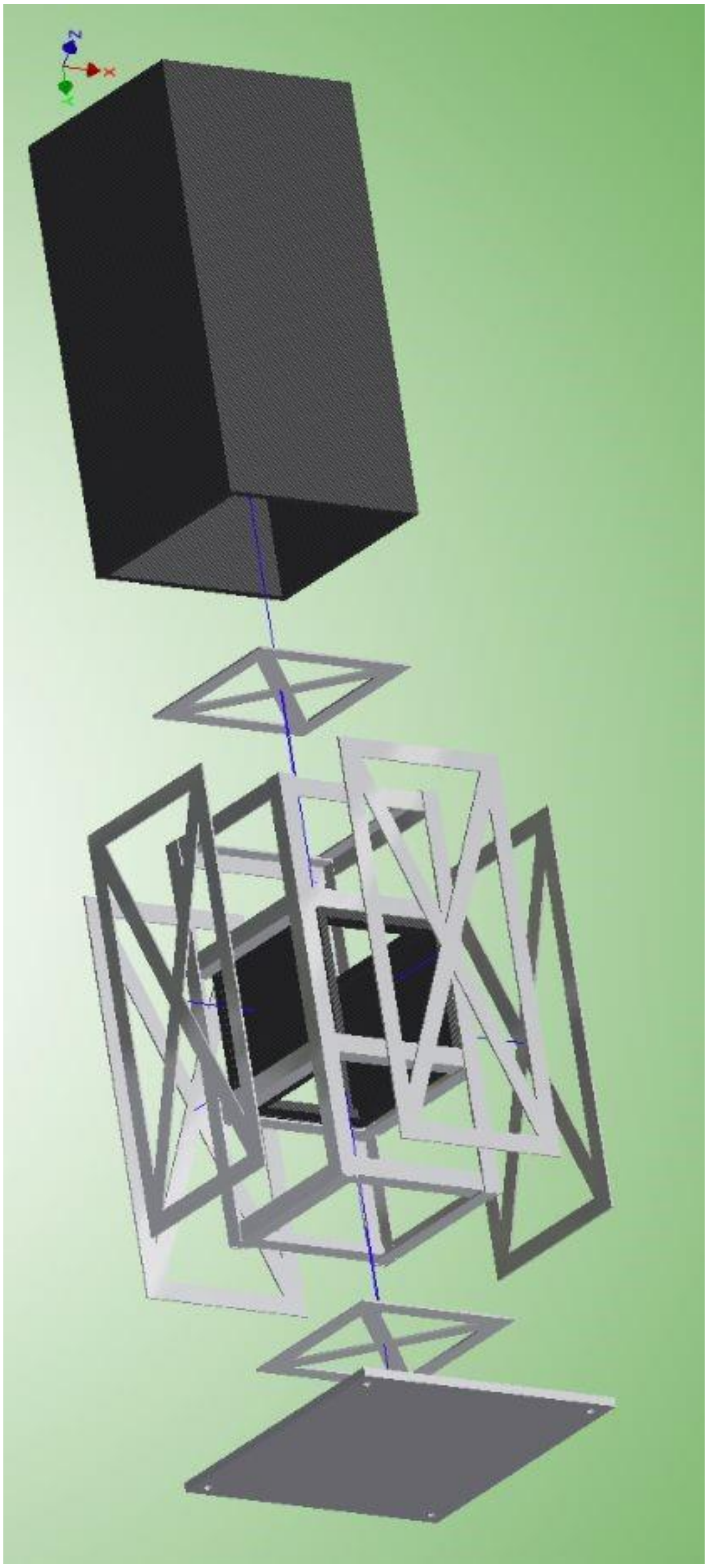


Figure 6. Full structure, exploded view

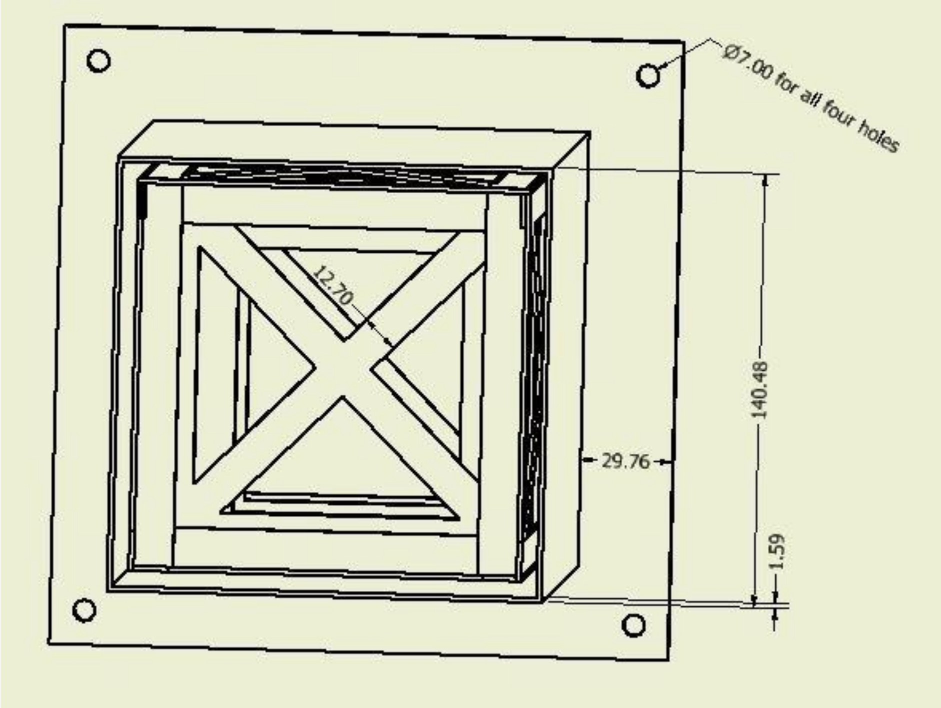


Figure 7. top 2D representation w/ dimensions (mm)

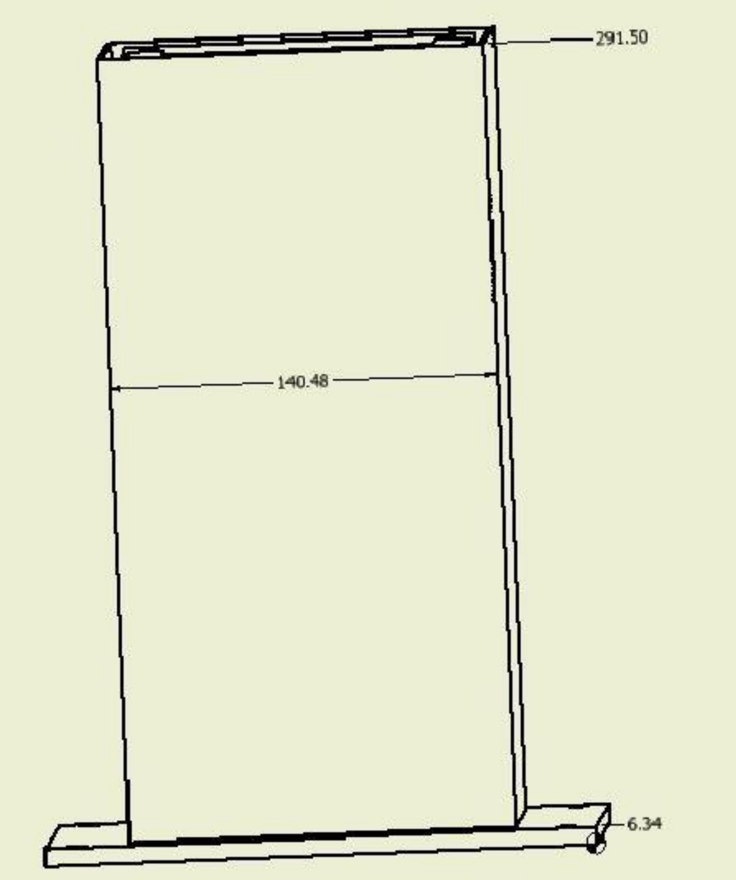


Figure 8. side 2D representation w/ dimensions (mm)

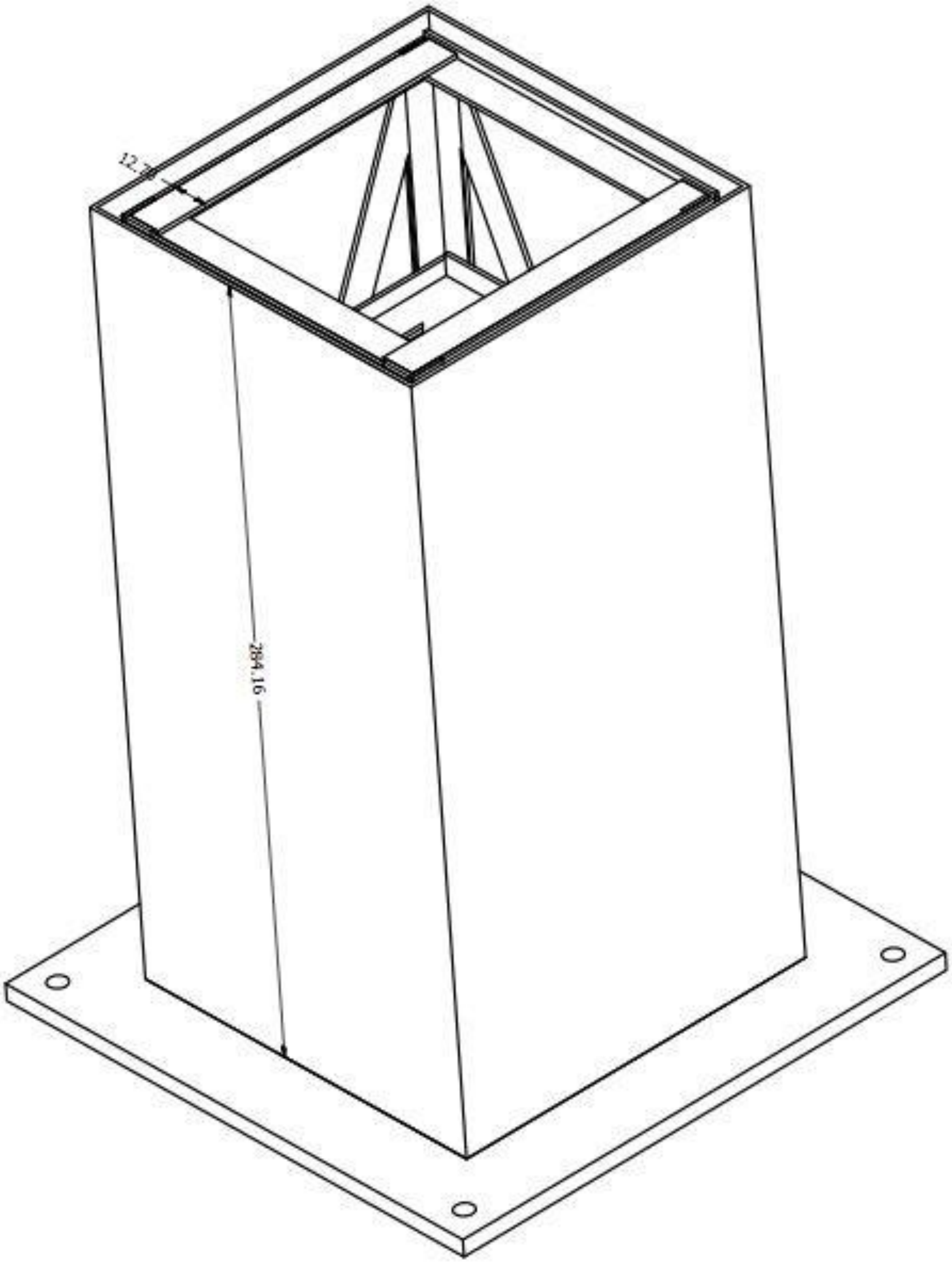


Figure 9. angled 2D representation w/ dimensions (mm)

Stress analysis

A preliminary stress analysis of the aluminum frame and box done using the Autodesk Inventor simulation platform yielded the following results for the 10G vertical shock and 5G horizontal shock:

5 G Horizontal Stress (150 N, 15 kg):

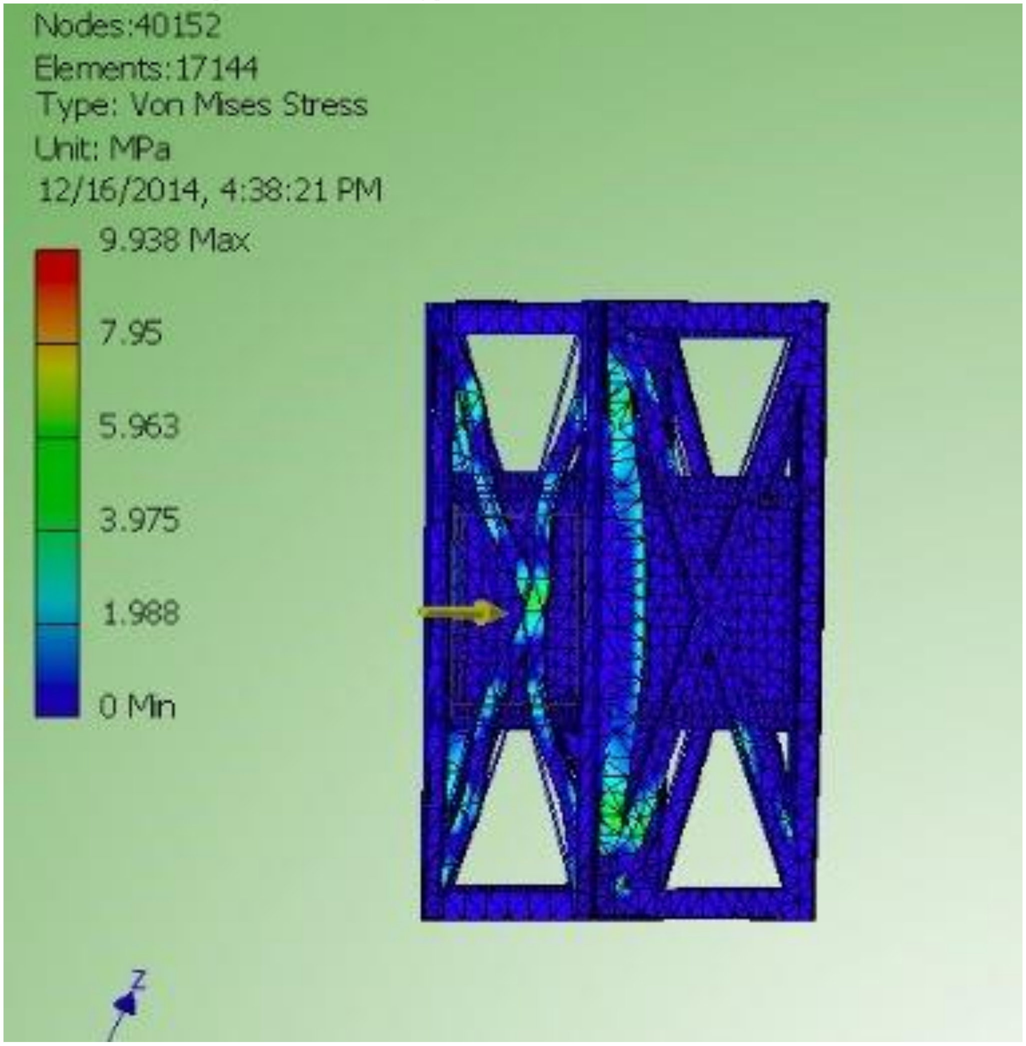


Figure 10. Horizontal stress

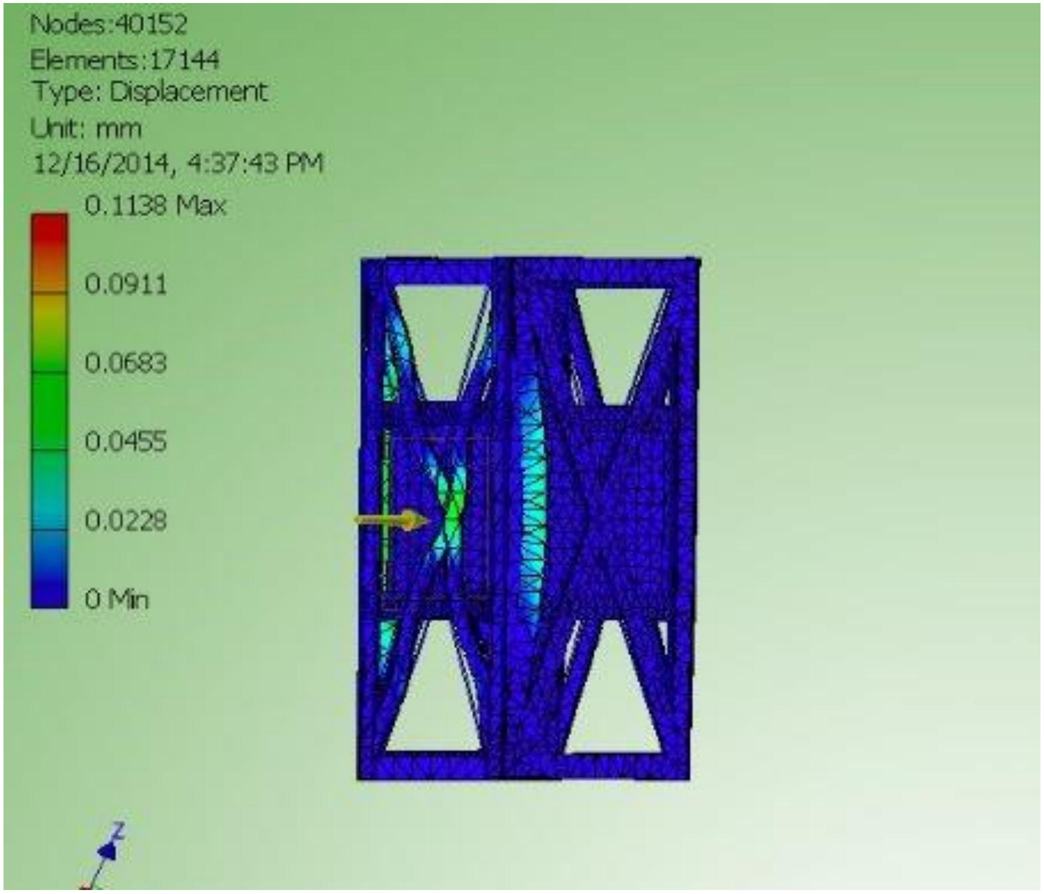


Figure 11. 5G Horizontal Stress Displacement

10G Vertical Stress (300 N, 30 kg)

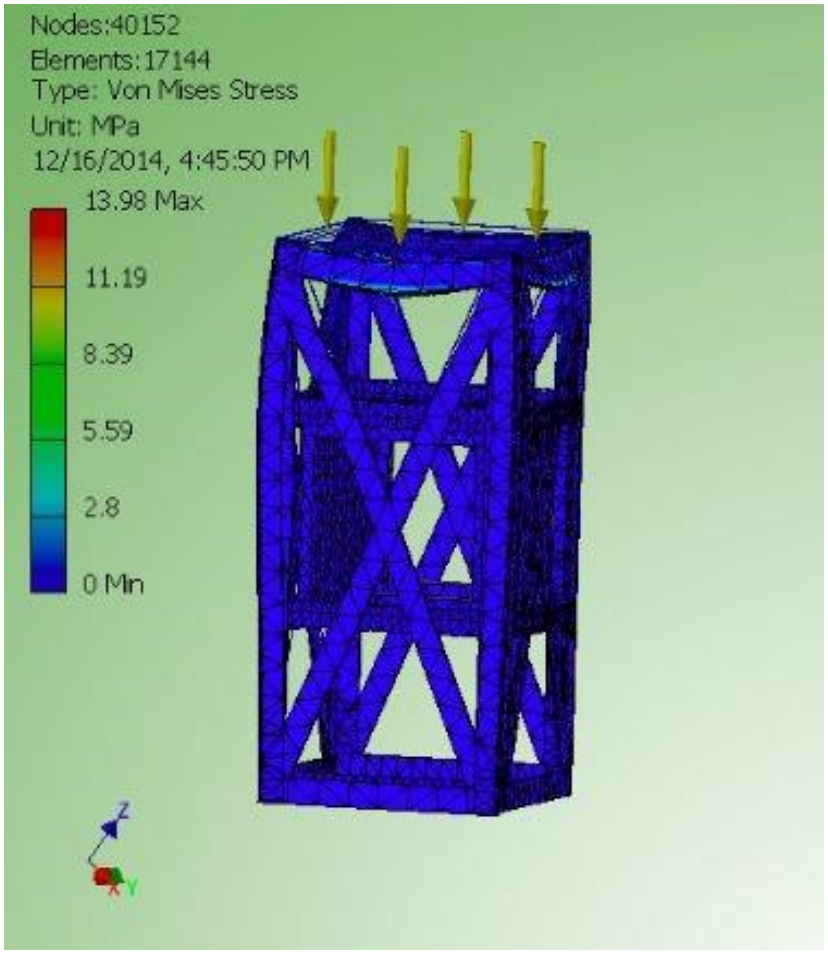


Figure 12. Vertical stress

The yield strength of this aluminum type is around 55 MPa. As can be seen, the max stress doesn't exceed 14 MPa, so we have a large safety margin. The structure should remain intact in the event of a substantial shock. Note that calculations are made assuming that the payload has a mass of 3 kg.

Weight budget

Reference	**Weight (kg)**
Outer Shell w/Lid	.402
Aluminum Frame	.661
Housing Case	.220
Base Plate	.268
Arduino Due	.036
Electronics	.5
TOTAL	2.417

Table 2. Weight budget of the payload

Data Transmission

Serial Port

We will use the serial port to transmit data and receive some basic commands.
The transmission will include the values gathered by the sensors. These values are:

- Temperature
- Humidity
- Pressure
- Light
- Energy values at different points of the system

This small quantity of information will easily fit within the 1200 baud bandwidth.
Regarding the uplink, few safety commands are planned. These are cutoff and control commands to ensure that a failing system will not compromise the entire mission. These commands will include cameras shutdown and communication system control commands (change of frequency and modulation).

Serial communications use a DB9 connector with pins 2 (receive / transmit), 3 (transmit / receive) and 5 (signal ground) connected. The protocol is RS232 and the port setup is 8 data bits, no parity, 1 stop bit and no flow control. The serial port is set to 1200 baud for small payloads. [Note that the term “baud” is used to designate the timing between bits on the serial link and is not necessarily your “bit rate”. Your “bit rate” is determined by the amount of data (the number of bits) you are transmitting on the serial line per unit time. In addition, your “bit rate” cannot exceed the “baud” rate. For example, suppose you have a small payload and are sending to HASP a data record of 45 bytes each minute. Your bit rate would be 6 bps (bits per second) and each bit would be sent at a “speed” of 1200 baud. HASP will collect data from the student payload as a bit stream: listening for, and receiving, data.

D-sub 9

In/out and diagram of DE9 connector (DB9 connector), commonly used for serial ports (RS-232).

Pin	SIG.	Signal Name	DTE (PC)
1	DCD	Data Carrier Detect	in
2	RXD	Receive Data	in
3	TXD	Transmit Data	out
4	DTR	Data Terminal Ready	out
5	GND	Signal Ground	-
6	DSR	Data Set Ready	in
7	RTS	Request to Send	out
8	CTS	Clear to Send	in
9	RI	Ring Indicator	in

Table 5. In/out diagram of DE9 connector

The DTE (PC) has the male connector (shown below), and the DCE (peripheral) has the female.

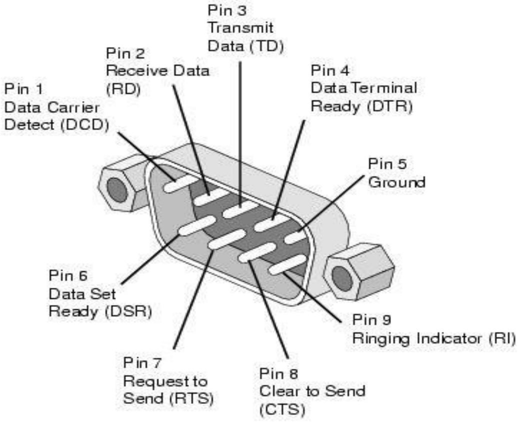


Figure 13. Male connector

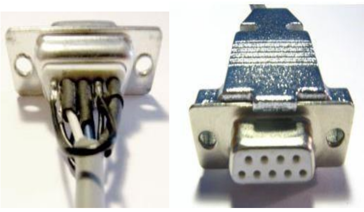


Figure 14. Female connector

RS-232 Maximum Cable Length

The maximum cable length for RS-232 is 50ft, but in practice depends on baud rate, cablespecific capacitance and ambient noise. The table below contains some rules-of-thumb from experiments done by Texas Instruments years ago.

Baud rate	**Maximum range / cable length**
19200	50ft
9600	500ft
4800	1000ft
2400	3000ft

Table 4. Baud rates and range relations

Communication System

For the data encoding, which will be sent to the communication system, we chose the AX.25 protocol. It is the most used protocol for other CubeSat projects around the world.

FLAG	ADDRESS	CONTROL	PID	DATA	FCS	FLAG
(0x7E)	(14 Bytes)	(1 Byte)	(1 Byte)	(0 – 256 Bytes)	(2 Bytes)	(0x7E)

Figure 15. AX.25 packet

Some characteristics of the protocol include a bit stuffing (add a 0 each 5 consecutive 1s) to avoid having the flag within the frame, and the implementation of several modes using the CONTROL and PID fields. This protocol will also be implemented in the Arduino.

Funding, Team management and Schedule

IIT's Ballooning Team is mainly supported by Armour College of Engineering and the IIT Student Government Association. Our team has been awarded more than $20,000 in the last three years and our two main sources of funding have already allocated funds for Scarlet Hawk IV. The Scarlet Hawk IV mission will be led by James Henry under the guidance of Dr. Murat Vural.

Half of the students currently involved in project are graduates students or are in the last year of a joint program and the other half are undergraduate students. The vast majority of the students are going to be attending IIT in 2015 and more students are going to be added throughout the spring semester.

This year's students come mainly from three departments: the Mechanical, Materials and Aerospace department, the Electrical and Computer Engineering department, and the Computer Science Department.

Teams Structure

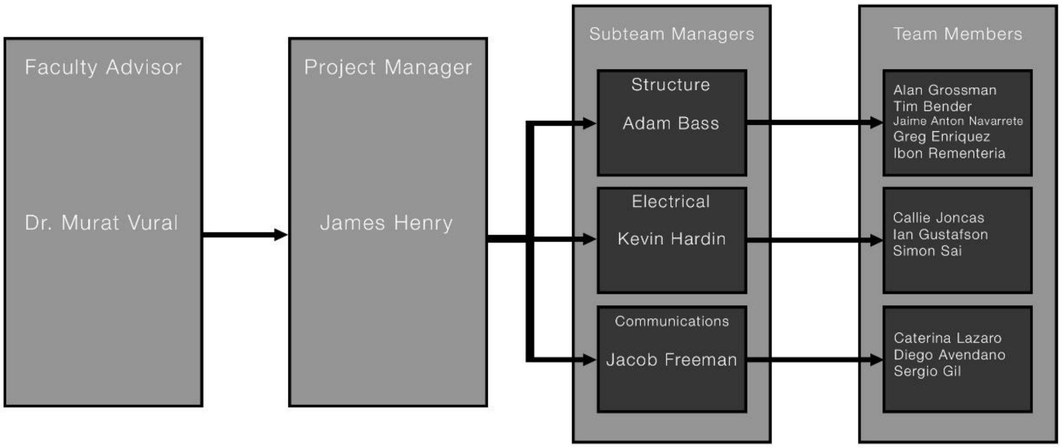


Fig 16. Distribution of students in teams

Schedule

There are nine main critical dates for the entire group, but each subsystem has its own internal deadlines. Important dates from the HASP Calendar (such as Integration Plan or Flight date) have served as guidance for the schedule elaboration. Using Scarlet Hawk I recommendations (HASP 2013), the schedule was done in such a way to reduce excessive workload and stress on each team wherever possible.

The workload will be organized bi-weekly or monthly, depending on the difficulty and dedication required for the task. Each subsystem is responsible for the completion of their milestone by the last Friday of each period. This will allow some time for the teams to exchange information, organize their next week's workload and, especially when two or more subteams need to collaborate, arrange new schedules.

NOTE: special weeks of IIT, such as the Spring Break (March 16th) and final exams (May 4th), have been respected.

November 2015	• Decide on experiment for 2016 mission • Organize groups and team leads
December 1, 2015	• Finalize electronics components list • Figure out structural needs
December 18, 2015	• Submit 2016 HASP proposal
February 2016	• Begin PCB design and order all remaining components • Begin CFRP cover design to improve on last year's
March 2016	• Order PCB boards and put together circuits • Begin work on software for Arduino and electronics • Cut and form FRP
April 2016	• Begin testing electronics subsystems, confirm accurate data readings • Attempt transmission and reception with communications subsystems. (Short range at first, incrementally increasing distance) • Finalize programming by April 15th • Test in vacuum chambers with assistance of Argonne
June 2016	• Improvement on systems and testing of full payload
September 2016	• Launch
November 2016	• Full Data analysis
December 2016	• Final Science and Technical Report