HASP Student Payload Application for 2016

Payload Title: HIDRA: High Altitude Data Relay Antenna

Payload Class: (check one) ☒ Small ☐ Large	Institution: Arizona State University	Submit Date: December 18, 2015

Project Abstract

The High-altitude Inflatable Data Relay Antenna (HIDRA) will be using a high-altitude balloon to collect data using an atmospheric sensing suite and then relay that data using an inflatable antenna as a technology demonstration in a space-like environment. The team will create a vertical profile of [CO2], temperature and air pressure. Then, using a FLIR camera, the team will collect data on urban heat islands and rural areas. Once the data are collected, it will be transmitted via the patch antenna as well as an inflatable antenna designed and constructed by the team. Once received, the data will be compared against each other to determine if an inflatable antenna can transmit data at the same data rate and quality as a traditional patch antenna. The science team will look at atmospheric [CO2] and any urban heat islands to see if there is a correlation between the two. The team will also compare collected data to previous studies to ensure congruency and accuracy of data. Once complete, it will be possible to determine if [CO2] affect urban heat islands and if an inflatable antenna is in fact a viable replacement for standard patch or mechanical antennas.

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1. Payload Description

1.1 Technology Objectives

HIDRA (High-altitude Inflatable Data Relay Antenna) will demonstrate science operations in a space-like environment using inflatable antenna technology. A primary mission goal is therefore to inflate a 50 cm diameter antenna and successfully transmit data from the payload to the ground station with equal or better fidelity than traditional antenna technology. In detail, the science data collected by HIDRA will be relayed to the ground using both the inflated antenna and a patch antenna and stored on the hard-drive onboard the balloon. In the event of science instrument failure, the hard-drive will be preloaded with data allowing the antenna to still be tested. The stored data will be compared with the data relayed to the ground using the inflatable antenna and patch antenna. Having a baseline of data from direct storage, to patch antenna, to inflatable, will allow us to determine the efficacy of the inflatable antenna compared to the patch antenna and also compared to the raw data.

1.2 Science Objectives

1.2.1 Science question

Is there a relationship between the Urban Heat Island (UHI) effect and CO_2 levels in the atmosphere?

1.2.2 Science goals

- Create a hyperspectral image cube using black and white (BW) and FLIR images.
- Create vertical profiles of CO_2 concentration with respect to temperature and pressure.
- Use data to create a UHI vs. CO_2 map using Geographical Information Systems (GIS).

1.2.3 Theory and background

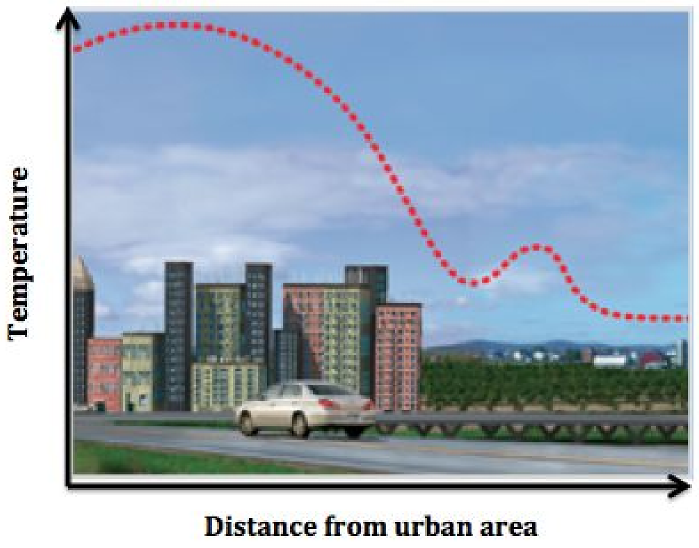

Figure 1.1 Qualitative graph showing the decrease in surface temperature with increasing distance from the urban area (modified after NASA; 3).

Urban Heat Island refers to an urban area, which is warmer than the surrounding rural areas, due to factors such as urban infrastructure (like dark roofs that absorb and retain heat), heat generated by automobiles, industries and population density (see **Figure 1.1**).

A study by Dousset et al. (2010) used maps from the United States Geological Survey's (USGS) Landsat satellite and land surface temperature data from the Moderate-resolution Infrared Spectroradiometer (MODIS) in order to quantify the Urban Heat Island effect. This study showed that the largest cities by both size and population densities have the strongest heat islands. Large population densities could also mean widespread use of air conditioning systems. The waste released by air conditioning systems elevate air temperatures of urban areas (see **Figure 1.2**; 1).

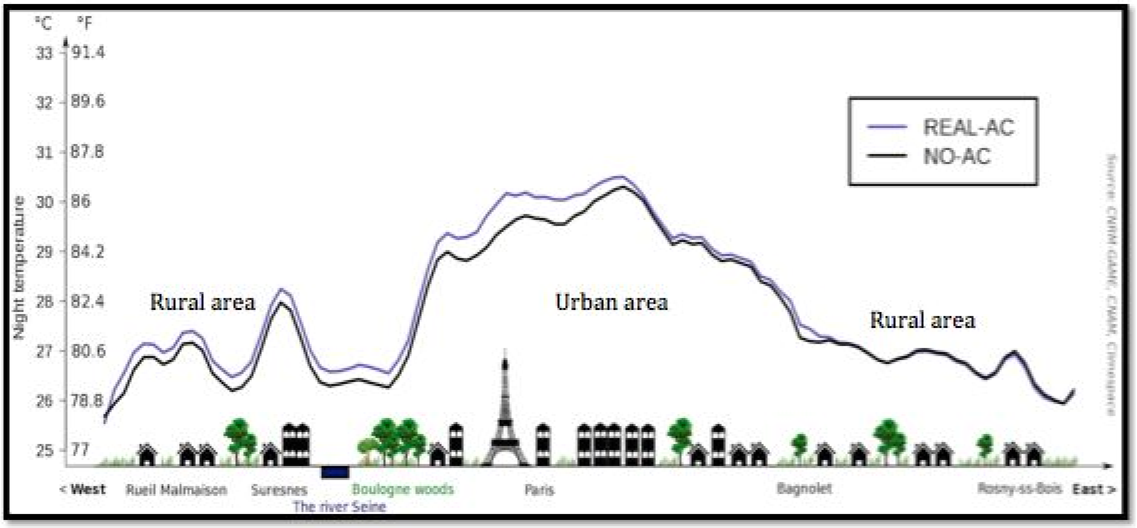

Figure 1.2 Night-time air temperatures over Paris and surrounding rural areas with and without air conditioning. The graph shows a positive correlation between air conditioning usage and increasing air temperature, particularly in urban (Paris) and sub - urban areas (1).

Although the Urban Heat Island effect is not a newly-discovered phenomenon, the uneven distribution of ground-based temperature sensors, which are prone to local bias, have eluded scientists from accurately quantifying the Urban Heat Island effect and comparing them this phenomenon between different urban areas nationally and globally.

1.2.4 Relevance

Determining if there is a relationship between CO_2 atmospheric concentration and Urban Heat Island is important as a majority of previous studies have largely focused on the relationship between albedo and population densities. Hence, determining if there is a relationship between CO_2 concentration and UHI will aid in finding better solutions to mitigate the UHI effect.

The results from this study will help us better understand how to accurately measure the UHI effect. With this information, a U.S. and world map of UHI and CO_2 concentrations can be created. Currently, there is no global UHI map, hence mapping the UHI along with CO_2

concentrations will not only enable us in determining if there is a relationship between the two but could also aid us in identifying areas with sustainable UHI. Moreover, we aim to create vertical profiles showing the CO_2 concentrations with altitude, temperature, pressure, and time of day. This data collected will be compared with published data. We can then analyze the data sets and see if there is a pattern of change during the durations of our experiment and past experiments.

1.3 Systems Overview

The interior of the payload will conform to the size and mass requirements set forth by the HASP Call for Proposals (15 cm × 15 cm × 30 cm and 3 kg). The upper part of the interior will contain the compacted antenna, benzoic acid chamber, piston deployment unit, interior pressure sensor for calibrating antenna inflation, and a black and white camera to confirm antenna inflation. At the bottom of the payload, two holes will be cut into the mounting plate to provide a downward view for a black and white camera and the FLIR camera. The rest of the interior will contain the atmospheric sensing suite, CO_2 sensor, inertial measurement unit (IMU), central processing unit (CPU), and power interface. See **Figure 1.3** for a diagram of sensor and system connections.

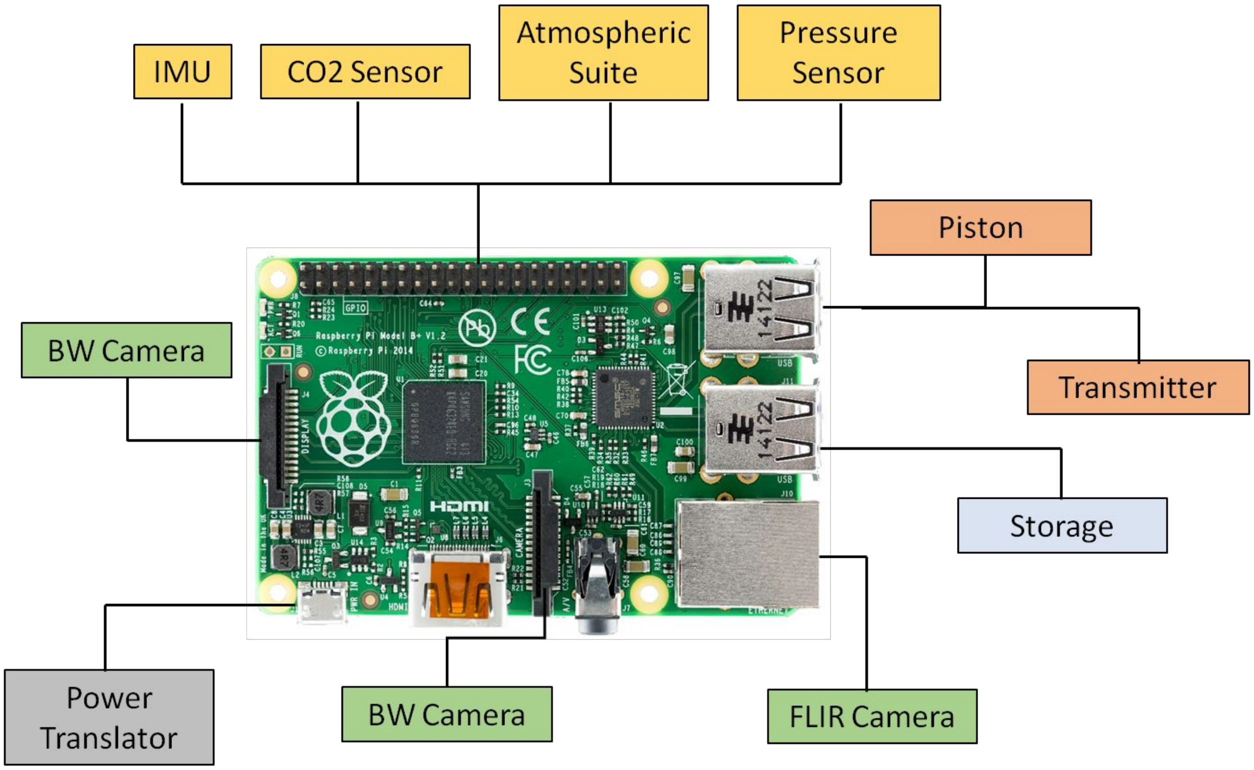

Figure 1.3 Diagram of connections to the central processing unit (Raspberry Pi B+).

1.4 Concept of Operations

The High-altitude Inflatable Data Relay Antenna (HIDRA) payload will be attached to one of the exterior arms of the NASA High Altitude Student Payload (HASP). As HASP ascends, the onboard barometric pressure, temperature and carbon dioxide Non-Dispersive Infrared (NDIR) sensor(s) will begin collecting data and storing it on the onboard computer. Simultaneously, the onboard camera(s) will begin taking footage at predetermined intervals. At an altitude of 15 km (TBR), a trap door on the payload will open to begin the process of antenna inflation which will take no more than 30 minutes. During the process of inflation, verification checks will be performed by a camera aimed at the anticipated maxima of inflation to determine if full antenna inflation has been completed. Upon completion of the inflation process, the onboard communications antenna and the inflated antenna will begin to transmit the data previously collected by the sensors and stored on the onboard computer to the ground station. The antenna will use the onboard computer to remain aimed at the ground station. Also transmitted will be image(s) taken by the camera(s). This process will continue until the HASP payload reaches its maximum height and begins to descend. At this point, the antennas will cease transmission and the payload will begin preparation for landing. See **Figure 1.4** for a visual representation of the concept of operations.

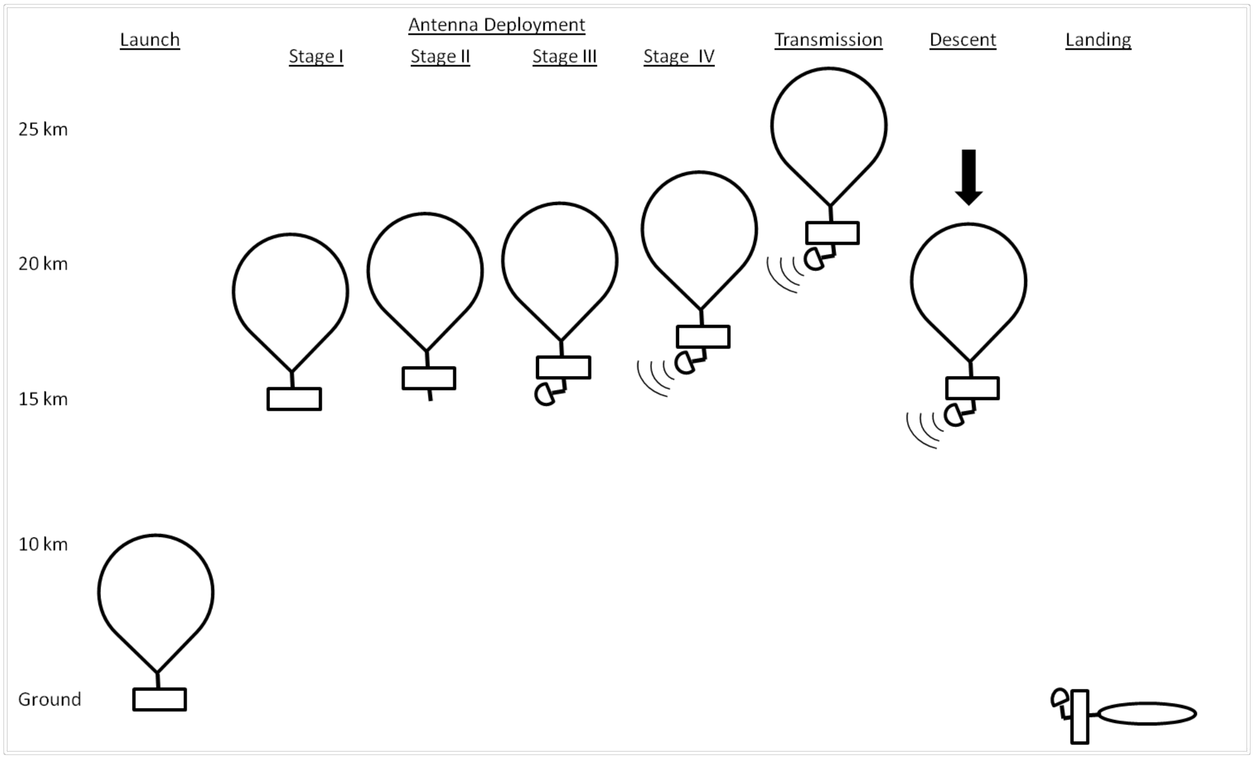

Figure 1.4 General overview of the concept of operations. Antenna design in this figure is different for ease of understanding the process of inflation and transmission.

2. Payload Specifications

2.1 Mass, Volume, and Power Budgets

Table 2.1 Preliminary mass, volume, and power budget with margins based off of constraints for HIDRA payload.

Component	Volume (cc)	Volume Uncertainty (cc)	Mass (g)	Mass Uncertainty (g)	Power (W)	Power Uncertainty (W)
Parallax MS5607 Atmospheric Suite	2	1	5	0.5	0.01	0.001
SenseAir S8 CO2 Sensor	6.5	1	8	2	0.15	0.015
FLIR A5 Thermal Camera	185	15	200	20	2.5	0.25
Adafruit Raspberry Pi Camera (x2)	4.5 (9)	1 (2)	4 (8)	2 (4)	0.05 (0.1)	0.01
Adafruit LSM9DS0 IMU	2	1	2.5	1	0.015	0.001
PCB 105C02 Pressure Sensor	2	1	2	0.5	0.0001	0.000001
Adafruit Raspberry Pi B+	81	10	45	5	2.5	0.25
Inflatable Antenna Array	1150	50	250	25	0	0
Inflation System	350	70	300	60	0.25	0.1
Thermal Protection	1500	500	40	10	-	-
Structure	150	20	400	80	-	-
Total	**3438**	**671**	**1261**	**208**	**5.525**	**0.627**
Constraints	6750	-	3000	-	15	-
Margin	49%	-	58%	-	63%	-

2.2 Modifications

The HIDRA payload requires that the mounting plate be slightly modified for the black and white and FLIR cameras. These require that there be ~2.5 cm (~1 in, for FLIR), and ~1 cm (~0.4 in, for BW) holes cut from the mounting plate. These holes will be cut within the allowed modification area on the mounting plate for small payloads (see **Figure 3.3**).

HIDRA includes a 50 cm (~20 in) diameter inflatable antenna that will be deployed from the top of the payload. Using this size of antenna will require a minimum of ~25 cm (~10 in) free space in all lateral directions. From **Figure 2.2**, the HIDRA antenna has over 70 cm (28 in) from the HASP main structure and payload 10, over 115 cm (46 in) from payload 01, and over 85 cm (~34.4 in) from payload 06 from the desired payload 05 position. Inflation of the antenna will not interfere with any surrounding payloads or HASP equipment.

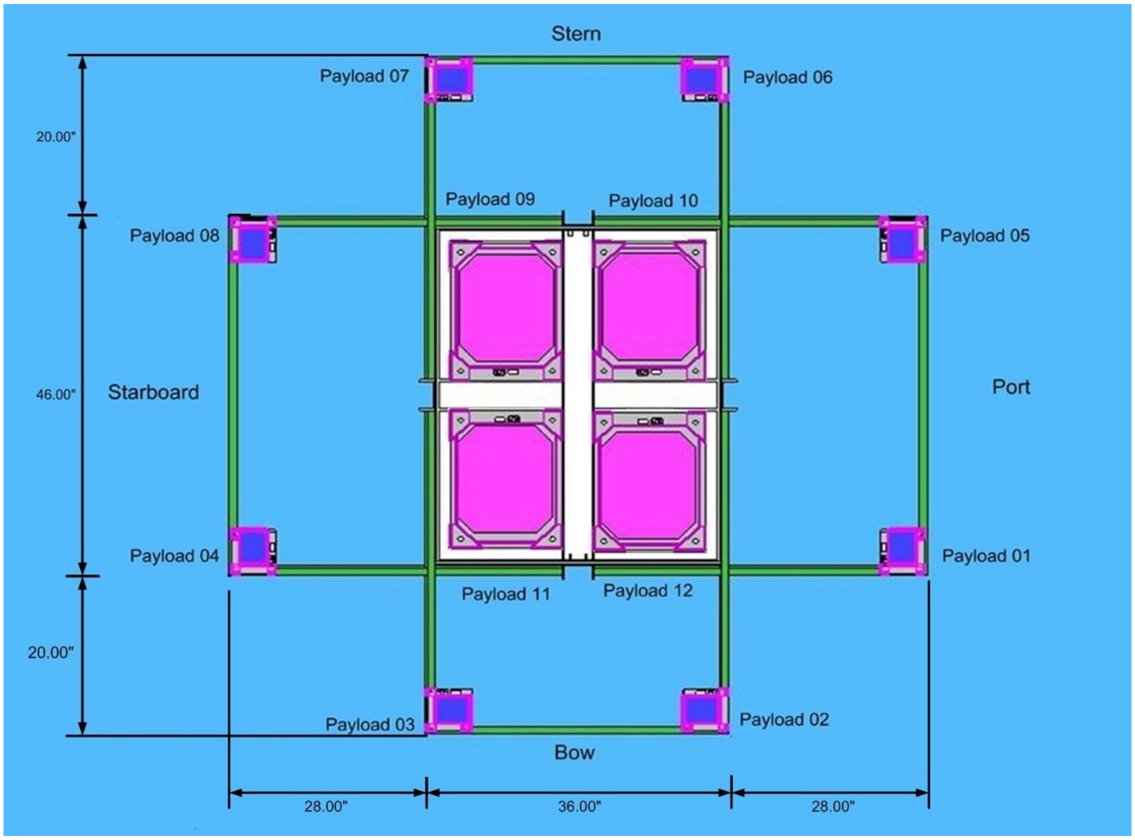

Figure 2.2 HASP payload layout. Units in inches.

2.3 Sensor Information

To meet the scientific objectives outlined in section 1.1, it was determined that the following instruments were necessary for the mission: an atmospheric sensing suite that could measure temperature and barometric pressure as well as determine altitude; a CO_2 sensor that in conjunction with the atmospheric suite can create a vertical profile; a thermal imaging camera to generate an infrared map of the Urban Heat Island effect; and a black and white camera to collect a visual image to create a hyperspectral image cube when combined with the thermal image(s).

(A second black and white camera of the same model will also be used for validating the inflation of the inflatable antenna.) After identifying mission constraints and needs and performing trade-studies for candidate instruments, the following have been selected. The Parallax MS5607 piezoresistor/thermistor was selected as our atmospheric sensing suite as it provides measurements from -40º C to 85º C and 10 mBar to 1200 mBar and has been successfully tested up to altitudes of 120,000 ft (36.6 km). The SenseAir S8 CO_2 sensor was selected due to its ability to collect measurements in the range of 0 - 10000 ppm combined with its small mass and power consumption. To fill the role of the thermal camera will be the FLIR A5 with a 25º × 20º field of view and 80 × 64 pixels which gives a ground sampling distance of about 166 m/pixel at a height of 30 km. Lastly, of the science instruments is the Adafruit Raspberry Pi black and white camera board which interfaces directly with the CPU via the two CSI ports.

In addition to the scientific instruments listed above, an inertial measurement unit (IMU) is also required for successful operation of the mission and the Adafruit LSM9DS0 was selected as it directly interfaces with the CPU and had the smallest volume and lowest mass of the IMUs researched. The last required sensor, is the internal pressure sensor that will be used in the interior of the inflatable antenna to control inflation via the piston, and continually monitor the inflatable to maintain full inflation via the piston mechanism. The Freescale Semiconductor MPL115A1 is the current front-runner for this sensor as it provides a larger pressure range than others researched, however additional trade-studies are expected for this sensor.

The instrument selection process was in conjunction with the CPU selection process. The primary requirement for the CPU was that it had enough and correct type of ports to interface with all of the instruments and that it did not draw exorbitant amounts of power. The Raspberry Pi B+ provides an adequate number of pins required to serve the CO_2 Sensor, Atmospheric Suite, IMU, and Internal Pressure Sensor. It also has an ethernet port to connect the FLIR camera to, enough USB ports for additional data storage and equipment, and contains two specially designed ports dedicated to cameras. See Figure 1.3 for a diagram of instrument and CPU interface.

2.4 HASP Interfaces and Channel Usage

The HIDRA team will utilize a self-built EDAC interfacing cable and circuit board in order to provide power to all of the onboard science instruments and computer. Power will be wired from the four channels (A, B, C, and D) which each provide 30 V, and will be adjusted with calculated resistance values per the four instruments receiving power. Subsequently, ground connections will be wired from the instruments back into the circuit board which will also be wired to the four channels (W, T, U, and, X) which each provide a grounding source (see **Figure 2.3**).

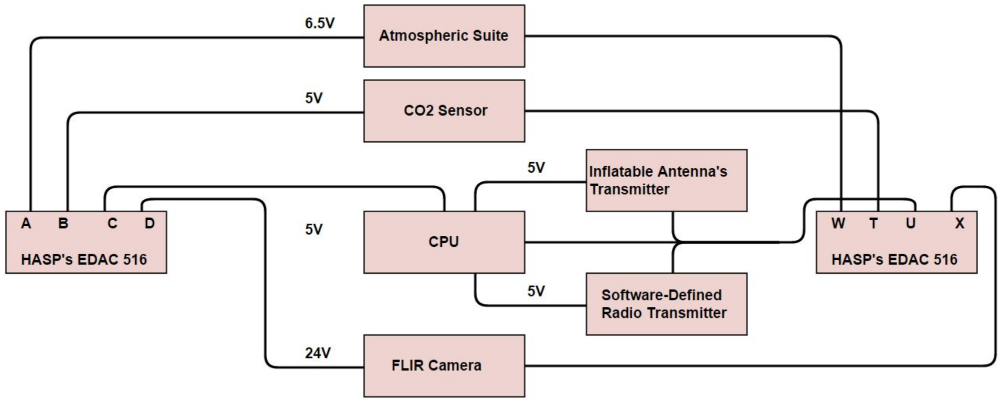

Figure 2.3 Circuit diagram of power and grounding dependencies

Since HIDRA is designed to autonomously run itself once powered, the HIDRA mission will not require channel usage from HASP. All onboard instruments, sensors, and mechanical systems will be programmed to function at predetermined intervals and/or altitudes and will be controlled via the onboard CPU.

3. Preliminary Designs and Drawings

3.1 Payload and Antenna Design

This option was chosen to be the primary design of the payload due to its simplicity and avenues for reduction in mass, volume, and cost. Because of the antenna being deployed from the top of the payload, the HASP mounting plate will not need to be altered to account for the antenna. Although, the mounting plate will still need to be altered for the black and white and FLIR cameras that are to be attached at the bottom of the payload (see Figure 2.1). Another BW camera, placed within the payload looking outward toward the antenna will be one of the two parts of the verification process, which ensures that the antenna inflated correctly and fully. The other part of the verification process is a pressure sensor that tracks the pressure within the antenna. Another benefit of this design is the shape of the reflector, and its ability to direct the signal to the ground station simply. This eliminates the need for a moving ground station. A working design is pictured in **Figure 3.1**.

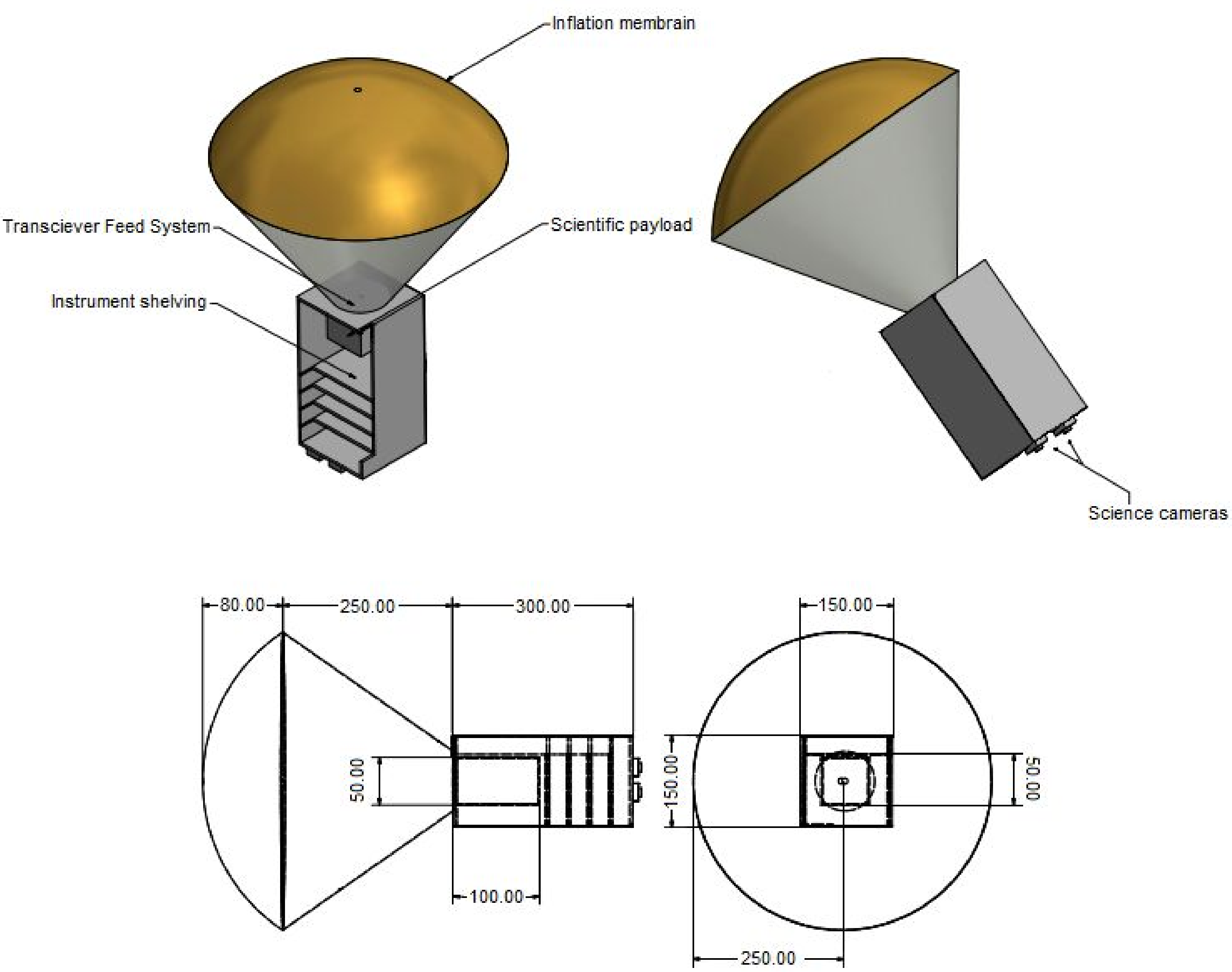

Figure 3.1 Conic reflector antenna design. Units in mm.

3.2 Power Circuit Diagram

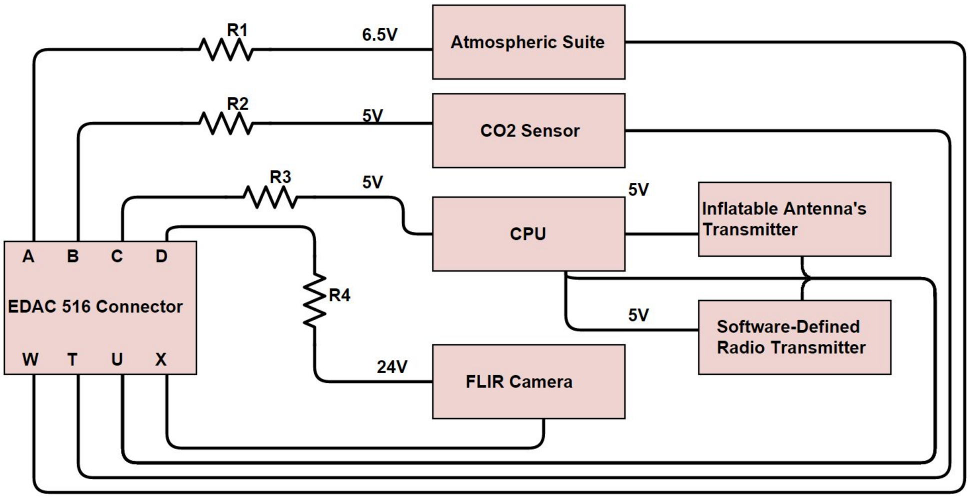

Figure 3.2 Power dependent instruments wired to the HIDRA-built EDAC interfacing circuit board and cable.

3.3 Mounting Plate Modification

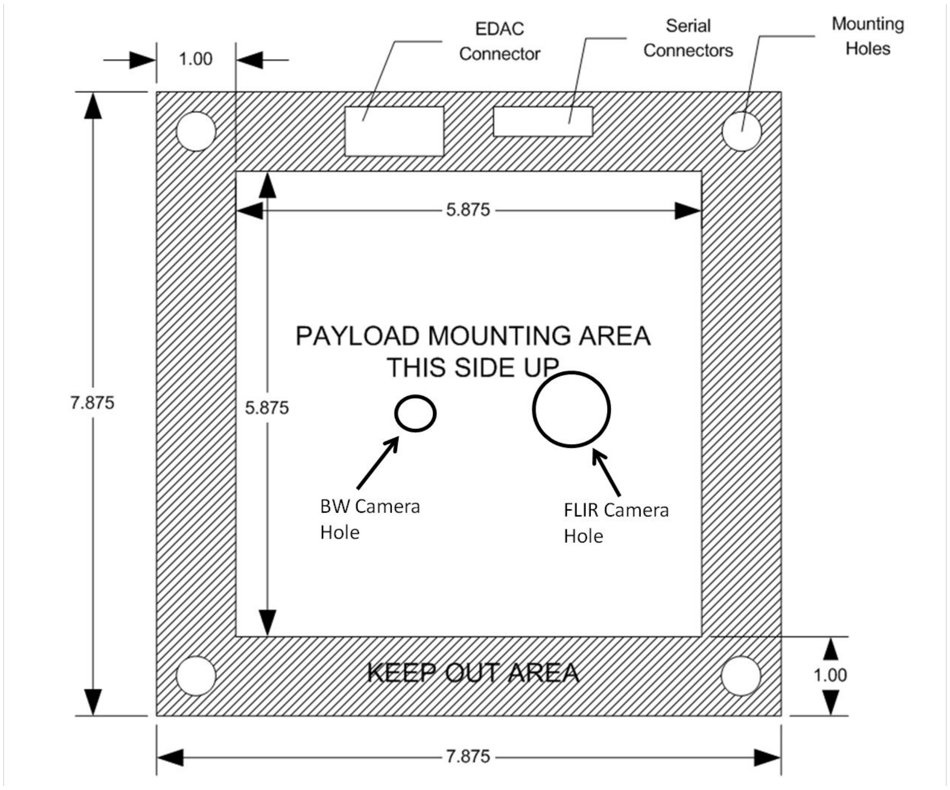

Figure 3.3 Example of proposed modification to mounting plate to allow cameras to aim downward. Units in inches.

3.4 Desired Payload Location

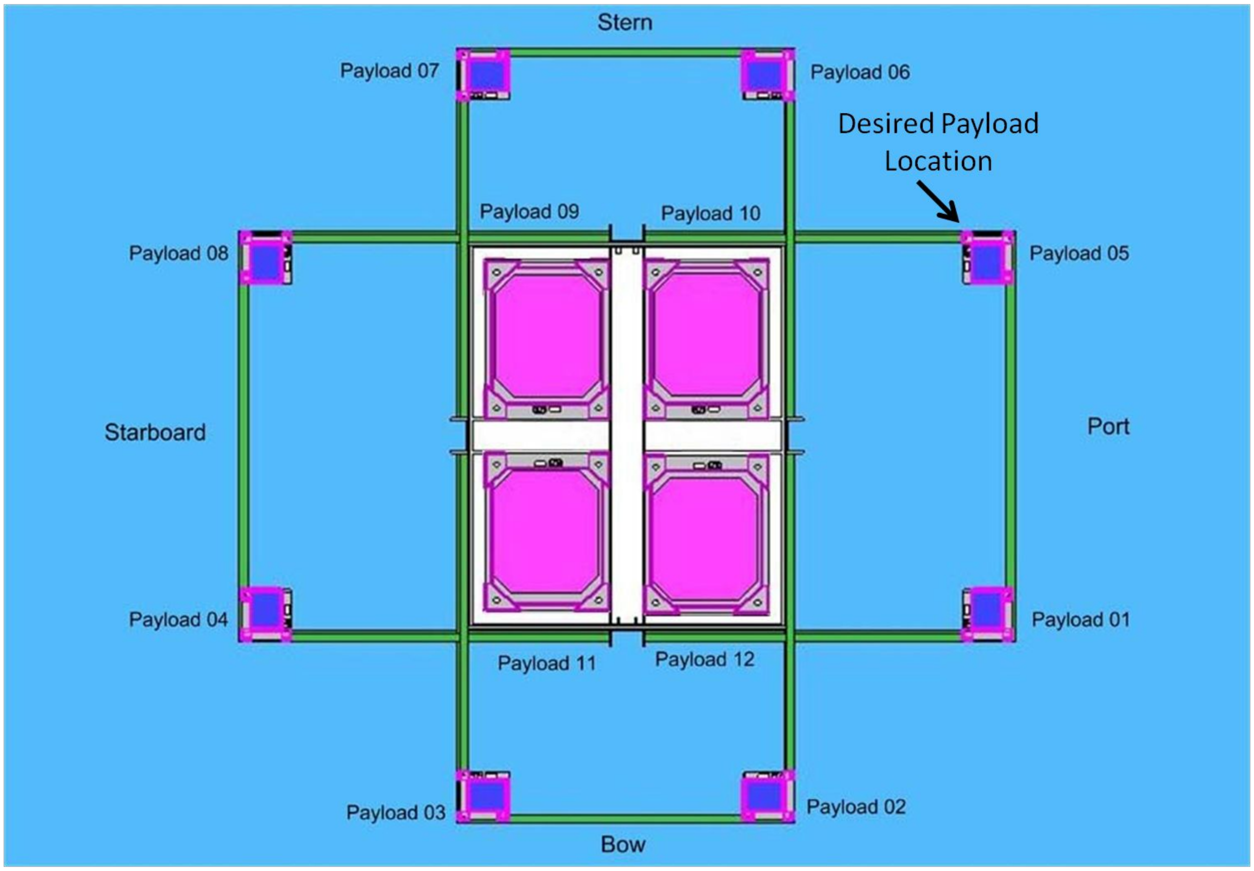

Figure 3.4: Diagram of HASP layout with HIDRA's desired payload location marked as Payload 05. The payload location will not affect payload orientation and payload can be placed at other locations if necessary.

4. Team Structure and General Timeline

HIDRA (High-altitude Inflatable Data Relay Antenna) will be designed and built as part of Arizona State University's School of Earth and Space capstone design course. Students in the class were split into two teams, one of them being HIDRA, and self-assigned mission positions according to strengths and interests. John McCulloch is responsible to team management and the overall project management of the HIDRA mission and specific mission areas are further split into sub-system teams overseen by team leads. Serving in an advisory role will be professors Erik Asphaug and Jekan Thangavelautham. The science and research team is composed of Candace Ashley Cheyenne Howard and is lead by Srinidhi Ravi. Bradley Karas and John McCulloch are responsible for the instrument selection and integration. The computers, software, and communications subsystems will be overseen by Jacob Trahan and Jia Zhuang which entails the programming of the CPU and integration of the instruments and antennas with the CPU to insure that the payload programming is self-sustained. The mechanical subsystem is managed by Alex Mastrean and Kelly Johnson and is responsible for the design and building of the inflatable antenna and all components thereof. Stone Hanlon will be responsible for the insulation and power control of the entire payload. Finally, Nathan Wilson and John Stone insure overall system integration and make sure all subsystems are within the constraints set forward by HASP. See **Table 4.1** for team hierarchy and and contact information.

At this point in time, it is anticipated that John McCulloch, Srinidhi Ravi, Alex Mastrean, and Jacob Trahan will travel to CSBF for payload integration and be present for flight operations at Ft. Sumner with the additional possibility of Kelly Johnson and Cheyenne Howard attending payload integration as well. **Table 4.2** gives a general overview of the timeline that the project will follow.

4.1 Team Structure

Table 4.1 Team structure, positions, and contact information for HIDRA personnel.

Project Manager Instruments Engineer	John McCulloch Undergraduate Student	Arizona State University ISTB4, Room 795 781 E Terrace Mall Tempe, AZ 85287-6004	jpmcull@asu.edu 602-565-6209
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Mechanical Systems Lead	Alex Mastrean Undergraduate Student	Arizona State University	amastrea@asu.edu 623-414-2207
Mechanical Design Lead	Kelly Johnson Undergraduate Student	Arizona State University	kejohn20@asu.edu 623-217-1952
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Research Scientist	Cheyenne Howard Undergraduate Student	Arizona State University	cheyenne.howard@asu.edu
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Systems Engineer	Nathaniel Wilson Undergraduate Student	Arizona State University	ndwilso4@asu.edu
Communications & Software Engineer	Jia Zhuang Undergraduate Student	Arizona State University	jzhuang3@asu.edu
Power/Thermal Engineer	Stone Hanlon Undergraduate Student	Arizona State University	sahanlon@asu.edu
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Faculty Advisor	Erik Asphaug Professor	Arizona State University ISTB4, Room 675 781 E Terrace Mall Tempe, AZ 85287-6004	easphaug@asu.edu 480- 727-2219

4.2 Milestone Timeline

Table 4.2 Preliminary schedule for HIDRA mission. (Milestones in bold.)

Month of 2015/2016	Tasks to be Completed
September	Define needs, goals, objectives, constraints and requirements. Develop mission concept (ConOps). **Mission concept review.**
October	System requirements review. Develop technology allocations. Establish preliminary design.
November	Verify preliminary design. Create detailed design.
December	Verify final design. **Preliminary design review.**
January	Finalize designs. Begin fabrication process. **Monthly status report.**
February	Complete frame and integration of major components. Complete preliminary model of antenna. **Critical design review. Monthly status report.**
March	Complete finalized antenna model. Integrate into completed payload. **System test readiness review. Monthly status report.**
April	Test all components. Rework failed test components. **Operational readiness review. Monthly status report. Preliminary PSIP document.**
May	Finalize tests, complete payload and prepare for HASP delivery. Prepare system for launch. **Flight readiness review. Monthly status report**
June	Ship to HASP. **HASP prep. Monthly status report**
July	**Final FLOP due. HASP prep. Monthly status report**
August	CSBF Integration. **Monthly status report**
September	Target flight ready. **Target Launch. Monthly status report**
October	Analyze results and begin science report.
November	Complete data analysis and final report.
December	Submit final report.

References

(1) de Munck, C., Pigeon, G., Masson, V., Marchadier, C. *The influence of air-conditioning on street temperatures in the city of Paris.* National Aeronautics and Space Administration. December 13. 2010. Web. November 16, 2015. <http://www.nasa.gov/pdf/505252main_demunck.pdf>.

(2) Dousset, B., Gourmelon, F., Giraudet, E., Laaidi, K., Zeghnoun, K., Bretin, P., Vandentorren, S.
Climate change and heat waves in Paris metropolitan area. National Aeronautics and Space Administration. December 13, 2010. Web. November 16, 2015. <http://www.nasa.gov/pdf/505253main_dousset.pdf>.

(3) Volland, A. *Satellite Pinpoint Drivers of Urban Heat Islands in the Northeast.* National Aeronautics and Space Administration. December 13, 2010. Web. November 16, 2015. <http://www.nasa.gov/topics/earth/features/heat-island-sprawl.html>.