HASP Student Payload Application for 2022

Payload Title: Application of Cosmic-ray Neutron Measurements to Determine Atmospheric Hydration and Surface Level Hydration	
Institution: Arizona State University	
Payload Class (Enter SMALL, or LARGE): **SMALL**	Submit Date: Jan.7

Project Abstract:
Cosmic rays constantly bombard Earth's atmosphere, shattering into a hail of hadronic, muonic, and electromagnetic components. Of all the components, neutrons are of great importance in understanding these atmospheric interactions. One of the main usages of these neutrons is for the detection of water on other terrestrial bodies and on our own. When fast neutrons strike a water molecule, half of the kinetic energy of the neutron is transferred into the hydrogen, slowing the neutron down and lowering its energy. This process is called moderation and by measuring the population of low and high energy neutrons, the relative abundance of water can be ascertained. Much like the LUNAH-MAP project that is tasked with water detection on the moon using a neutron/gamma ray detector, the HART team aims to map out the neutron flux and hydration at altitude and correlate it to neutron flux and ground level hydration in order to get a better understanding of cosmic ray interactions in dense atmospheres and water detection.

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Flight Hazard Certification Checklist

NASA has identified several classes of material as hazardous to personnel and/or flight systems. This checklist identifies these documented risks. Applying flight groups are required to acknowledge if the payload will include any of the hazards included on the l hun ist below. Simply place an (x) in the appropriate field for each hazard classification. **Note:** Certain classifications are explicitly banned from HASP (grey filled items on table below) and the remaining hazards will require additional paperwork and certifications. If you intend to include one of the hazards, you must include detailed documentation in section 3.8 of the application as required by the HASP Call for Payloads.

This certification must be signed by both the team faculty advisor and the student team lead and included in your application immediately following the cover sheet form.

Hazardous Materials List		
Classification	**Included on Payload**	**Not Included on Payload**
RF transmitters		X
High Voltage		X
Lasers (Class 1, 2, and 3R only) Fully Enclosed		X
Intentionally Dropped Components		X
Liquid Chemicals		X
Cryogenic Materials		X
Radioactive Material		X
Pressure Vessels		X
Pyrotechnics		X
Magnets less than 1 Gauss		X
UV Light		X
Biological Samples		X

Batteries		**X**
High intensity light source		**X**

Student Team Leader Signature: ______________________________

Faculty Advisor Signature:

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Acronyms and Abbreviations

Acronym	Definition
HASP	High Altitude Student Platform
HART	High Atmosphere Research Team
SESE	School of Earth and Space Exploration
ASU	Arizona State University
FPGA	Field Programmable Gate Array
CLYC	Cs_2LiYCl_6:Ce
STBM	Standby Mode
Mini-NS	Miniature Neutron Spectrometer
DAQ	Data Acquisition
PSD	Pulse Shape Discrimination
PLMa	PhyMetrix Loop-powered Moisture analyzer/Hygrometer
HART Commands	Highway Addressable Remote Transducer Commands
WMO	World Meteorological Organization
NOAA	National Oceanic and Atmospheric Administration
SRR	System Requirements Review
PDR	Preliminary Design Review
CDR	Critical Design Review
SIR	System Integration Review
ORR	Operational Readiness Review
PFAR	Post-Flight Assessment Review
RFA(s)	Request(s) for Action
CPS	Counts Per Second

Table 1. Acronyms

1. Payload Description

1.1 Payload Scientific / Technical Background

The High Atmospheric Research Team (HART) was established by undergraduate students at Arizona State University's (ASU) School of Earth and Space Exploration (SESE). Supported by NASA, SESE, and ASU's LunaH-Map team, HART's goal is to deepen the understanding of relationships between atmospheric and surface environments. This project utilizes various instruments including a CPU, hygrometer (donated by SESE), thermometer, and miniature neutron detector (donated by the LunaH-Map team). Each instrument is individually calibrated and integrated onto a payload for the purpose of collecting *in-situ* data to validate HART's science objectives. Data will be collected during the High Altitude Student Platform (HASP) flight launching at Fort Sumner, New Mexico in the summer of 2022. The HASP Management team, NASA Balloon Program Office, and Louisiana Space Consortium supports eight small payloads of ~3 kg weight that will be carried to altitudes of ~36 km for durations up to 20 hours.

Hydrogen is one of the most abundant elements found throughout the universe. Present in Earth's atmosphere and interior, Hydrogen is mainly fused with other elements which generates large amounts of hydrocarbons and water. When determining the concentration of hydrogen in the atmosphere, it is crucial to consider the two variables that control its availability: soil moisture and air humidity. Influenced by precipitation, soil properties, and temperature, soil moisture pertains to the amount of water stored in the soil. Whereas air humidity is the amount of water vapor present in the air. HART will focus on the parallels between hydration levels of the atmosphere and on the surface.

HART's primary objectives are to determine if there is an identifiable correlation between surface level hydration and neutron counts, and a correlation between atmospheric hydration and atmospheric neutron counts. Atmospheric neutron counts will be collected from the thermal and epithermal range in the upper stratosphere. Surface level and atmospheric hydration are measured by the total water vapor present in a given volume of air (absolute humidity). A hygrometer will be used to measure atmospheric hydration, whereas current ground data from weather stations and soil moisture will determine surface level hydration.

Before launch, polyethylene will shield the neutron sensor and the neutron count rate will increase by an order of magnitude. HART expects the neutron count rate to be approximately $3 \pm 1\ cps\ cm^2 s^{-1}$ at 1 km above sea level and $40 \pm 10\ cps\ cm^2 s^{-1}$ at 36 km above sea level. *Ex-situ* data analysis of water content and changes in atmospheric neutron counts has the potential to reveal relationships between surface level and atmospheric hydration. If a correlation is discovered, this project could provide a fundamental understanding about the concentration of hydrogen in the atmosphere. In addition, correlations between surface level and atmospheric hydration could promote further analysis on weather research and predict the productivity of the hydrological cycle. Furthermore, this project has the potential to aid in climate research and predict droughts and potential rainfall events.

1.1.1 Mission Statement

The heart of our payload (dubbed the HART box) contains the newest generation of the Mini-Neutron Spectrometer (Mini-NS) instrument, following up on the latest designs of the LunaH-Map neutron spectrometer that is to be launched in 2022. The HART box will be taking data throughout the entire duration of the flight, analyzing both neutron flux and relative humidity.

The HART team will fly a neutron detector, temperature probe, and hygrometer on a small payload of 3 kg weight to an altitude of 36 km (120,000 ft) from Ft. Sumner New Mexico, to determine if there is a correlation between neutron flux and hydration on the ground and at altitude. *Ex-situ* data analysis of water content and changes in neutron flux could reveal relationships pertaining to the availability of hydrogen in the atmosphere and on the surface of Earth.

1.1.2 Mission Background and Justification

HART's mission aims to define any correlations between surface level neutron counts and surface level hydration against atmospheric neutron counts and atmospheric hydration. Prior studies have focused on analyzing hydrogen with neutron spectrometers on other planetary bodies at low altitude elliptical polar orbits, such as the moon. However, these projects lack the capacity to address analyzing hydrogen on a habitable body like Earth.

Hydrogen, the lightest element on the periodic table, consists of protons and electrons. In addition, the hydrogen atom has the same mass as one single neutron. When measuring neutrons, it is important to consider that hydrogen is a neutron moderator due to the law of conservation of momentum. When a neutron strikes a molecule of similar mass (such as one proton in hydrogen), more of its kinetic energy is transferred to the proton than if it struck a more massive molecule, thus it is more likely to lose energy with each collision in a hydrogen-rich space. Hydrogen is very abundant on Earth in the form of water, which is known to be a highly effective moderating material. Therefore, we would expect to see fewer, low energy neutrons when passing through water and faster moving neutrons in drier air. When detecting and determining the amount of neutrons in the epithermal and thermal range, the miniature neutron detector does not 'count' neutrons. Instead, it collects neutron events that take place throughout the flight. (Refer to 1.5, Data Acquisition and Figure 1).

To answer our science questions and relate neutron counts to ground level moisture, we need to collect data on absolute humidity and soil moisture below the flight path of the balloon to determine the total amount of water in the area below the payload.

To determine the absolute humidity in the area below the balloon, we will collect data updated on an hourly basis from weather stations compiled by timeanddate.com, which consists of weather data from airports, World Meteorological Organization (WMO) stations, and National Oceanic and Atmospheric Administration (NOAA). After the flight we will locate the nearest weather stations in cities and landmarks close to the flight path, and record conditions of relative humidity, temperature, and pressure correlated to the time of flight. Relative humidity can be converted to absolute humidity (units kg/m^3) with the equation $\rho_w = e/(R_w T)$, where ρ_w is absolute humidity, e is the saturation vapor pressure (calculated with temperature and pressure), R_w is relative humidity, and T is temperature. We will assume these conditions are representative of the conditions in a certain radius of the data source, and use multiple sources where appropriate to approximate the average conditions in the footprint of the detector.

To determine soil moisture, we can use tools provided by NOAA (PSL Data: CPC Soil Moisture) to model soil moisture as a monthly average. Data from these models can be downloaded to determine the soil moisture in the same area used to take measurements for absolute humidity. Soil moisture changes very slowly in the absence of major precipitation events, so real-time measurements will not appreciably increase our accuracy. These measurements are given in mm (water height), which can be converted to kg/m^2 to determine the absolute amount of water below the surface in the footprint area of the payload.

By adding these measurements together we can compare neutron flux from the detector with the total amount of water at ground level, to see if there is any correlation indicating neutrons that are moderated by water near the ground can be detected from high altitude.

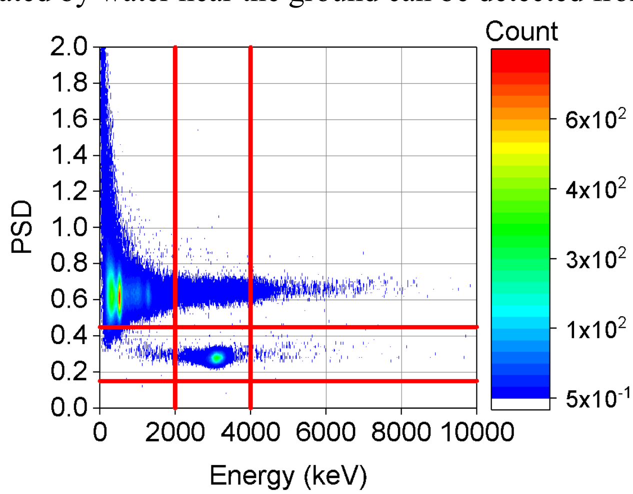

Figure 1. Example figure of plotted events with PSD vs Energy. The large swath of blue and green above 0.4 PSD are gamma ray events. The boxed collection of blue and green at 0.3 PSD and at an energy range of 2000 keV and 4000 keV are neutron events.

1.1.3 Mission Objectives

HART's mission has six objectives:

Objective 1: Map neutron flux during the duration of the flight.

Objective 2: Map temperature gradients during the duration of the flight.

Objective 3: Map hydration gradients above 20 km (to ensure there is no oversaturation of measurements).

Objective 4: Calculate absolute humidity of surface level and soil moisture content from ground data.

Objective 5: Correlate changes in neutron flux with hydration gradients to determine if there is an identifiable relationship between surface level hydration and neutron counts.

Objective 6: Correlate changes in neutron flux with hydration gradients to determine if there is an identifiable relationship between atmospheric hydration and atmospheric neutron counts.

1.2 Payload Systems and Principle of Operation

HART's payload will consist of a Raspberry Pi Zero, PLMa hygrometer, thermometer, and miniature neutron detector in an aluminum 6061 box, which is complimented with power from the HASP Gondola and a heater. HART is responsible for the payload build and full system testing. The miniature neutron detector is responsible for collecting neutron related measurements throughout the entire flight. The PLMa hygrometer is responsible for detecting atmospheric humidity and temperature. These datasets will then advance to the Raspberry Pi Zero, where the information will be stored to a downlink file. The Raspberry Pi Zero will control all of the subsystems and the entire payload. *Figures 2-5* depict a block diagram, software, the interior of the payload, and a concept of operations diagram which demonstrate a step by step process of how the payload will operate.

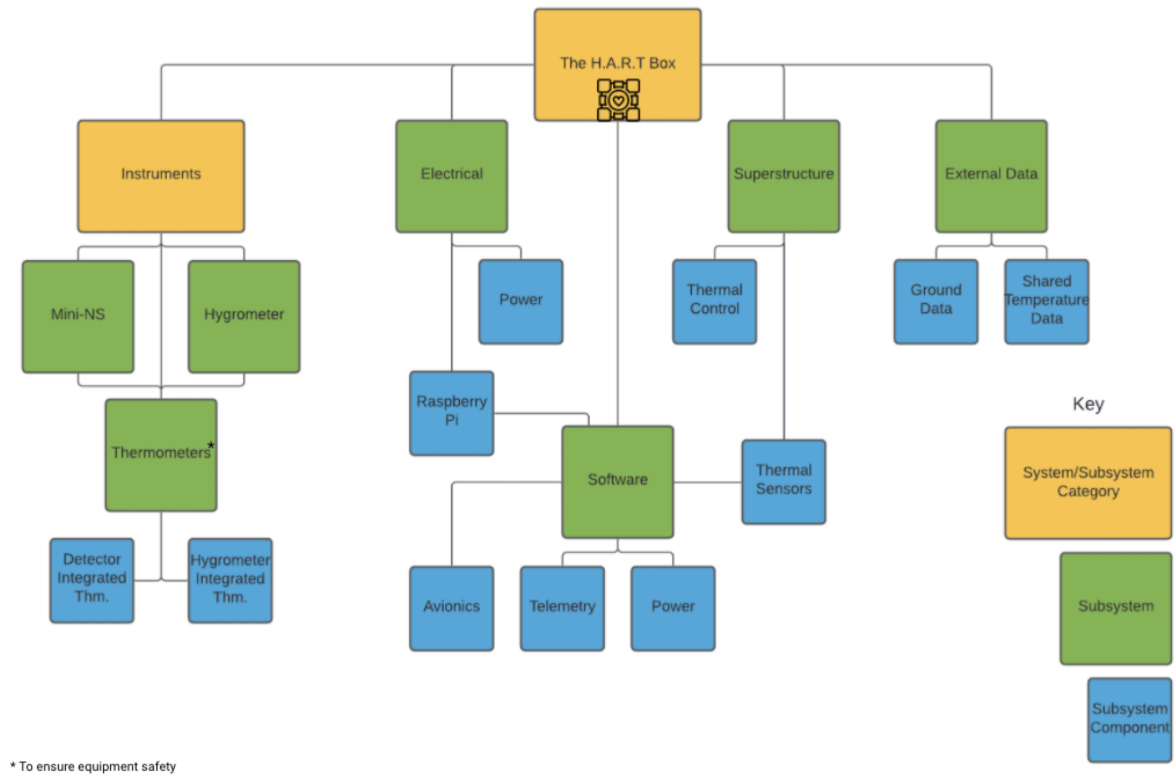

Figure 2: A block diagram that provides an overview of the entire payload.

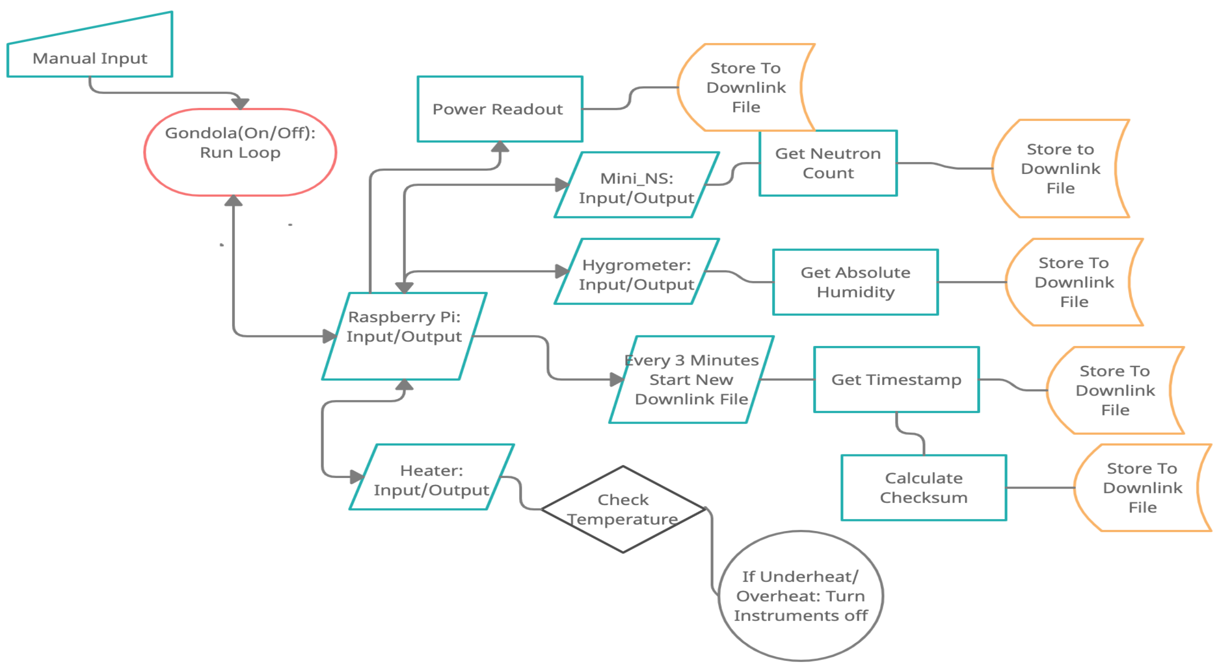

Figure 3: This figure shows an overview of the software pertaining to the subsystems.

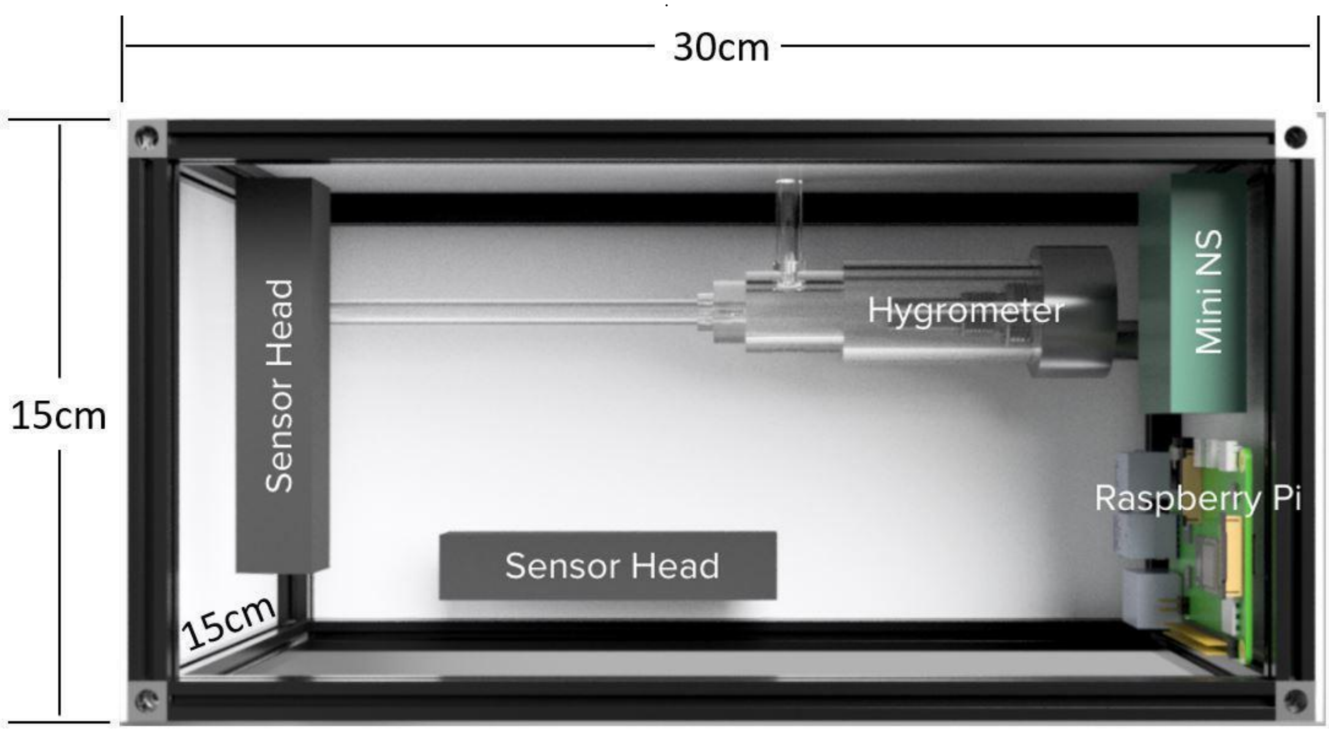

Figure 4: The interior of HART's small payload. Dimensions: (150 x 150 x 300)mm

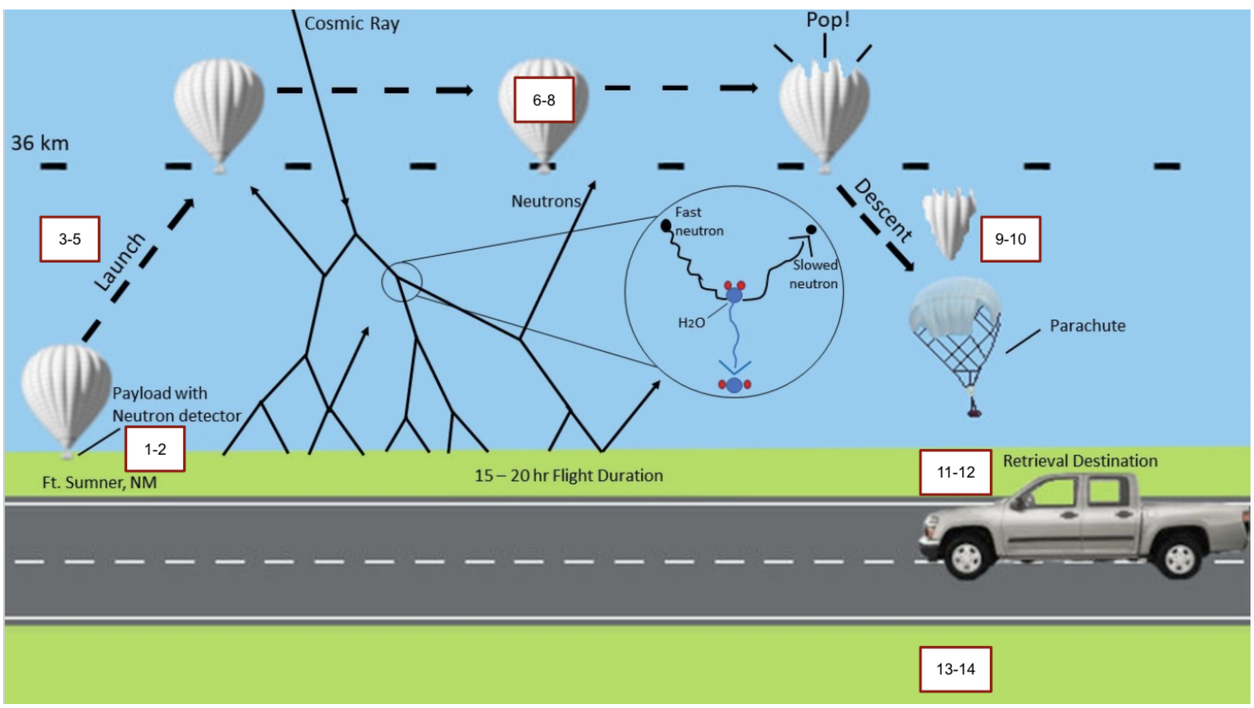

Figure 5: Conops diagram. Use with Figure 6.

Stage Number	Description
1	**Vacuum/Temperature Testing** Test both Mini-NS and PMLa to see if they can withstand both extreme temperature and pressure regimes.

2	**Ancillary Data** Obtain hydration data for local area surrounding launch site NOAA/NASA telemetry, for a rough estimate of what to expect.
3	**Detector Activation** Begin the startup sequence and calibrate for background noise.
4	**Hygrometer Activation** Begin startup sequence to stand by mode (STBM). Hold in STBM until altitude is greater than 17 km.
5	**Temperature Probe Activation** Begin recording thermal data upon vehicle release.
6	**Detector Nominal** Begin recording neutron counts of both thermal and epithermal events over timed intervals of 20 minutes with 10 minutes. or rest to send a statement of health and mean value for the latest measurement window to the pi module.
7	**Hygrometer Activation** Exit STBM and begin recording absolute humidity at intervals of 100 samples per second once altitude has reached less than 17 km. Send a statement of health and the latest humidity value to the pi module.
8	**Temperature probe Nominal** Continue temperature fluctuation readings in intervals of one per minute.
9	**Detector Deactivation** Upon receiving the flight termination command from HASP, the detector will enter STBM or will be powered off.
10	**Hygrometer Deactivation** Upon receiving the flight termination command from HASP, the analizer will enter STBM and then will be powered off.
11	**Payload condition check** Ensure the payload is in operating condition and has not been compromised during flight.
12	**Data condition check** Ensure that the data has been successfully written to the storage system onboard the Pi module.
13	**Data Analysis** Comb through the data and ensure cohesive results and collect hydration data for regions under flight path.

14	**Model construction** Create a program that reads the data and provides an accurate representation of the flight.

Figure 6: Explanation of conops diagram. Use with Figure 5

1.3 Major System Components

Avionics:

Our avionics system consists of a Raspberry Pi Zero, which will be connected to all other internal systems as well as the HASP interface. It will send commands to our components, receive and store data, and also send out statements of health through to the HASP system.

Neutron Detector:

The neutron detector consists of two FPGAs (readout electronics) and two CLYC crystal sensor heads that are coupled to photomultiplier tubes which amplify the signal, finally sending the data to the readout electronics. The detector will be shielded with polyethylene to acquire a larger sampling size of neutrons. Fast neutrons that interact with the detector without shielding will simply pass through the CLYC crystal without being recorded as an event. With shielding it is estimated that the detector will be able to detect events one order of magnitude greater than what was originally calculated, from 4 counts per second to 40 counts per second at an altitude of 36 km.

Hygrometer:

The hygrometer that will be utilized will be the Phymetrix PLMa. When air flows into the pores of the nanopore sensor, the sensor analyzes the amount of water vapor molecules. This amount is proportional to the partial water vapor pressure of the gas surrounding the sensor, and the partial water vapor pressure is dependent on the total pressure and water vapor content of the gas. To ensure an accurate measurement, the instrument will be in a PhyMetrix SC-1 Sample Cell casing. This casing will be exposed to the outside environment of the payload to ensure flow of water vapor. To prevent contamination and impact of measurements, stainless steel tubing will be used at the exhaust port to ensure that the high polarity of the water molecules does not create a backflow into the system.

1.4 Mechanical and Structural Design

Our design will be a 150 x 150 x 300 mm rectangular box, with 1.5 mm thick sheets of aluminum 6061 on all sides. The skeleton holding the aluminum will be T-slot beams cut to length for each corner. Aluminum sheets will be held onto the T-slot beams via L brackets at each corner with M3 machine screws.

Figure 7: Box design. Dimension: (150x150x300)mm. See figure 19 for dimensional drawing

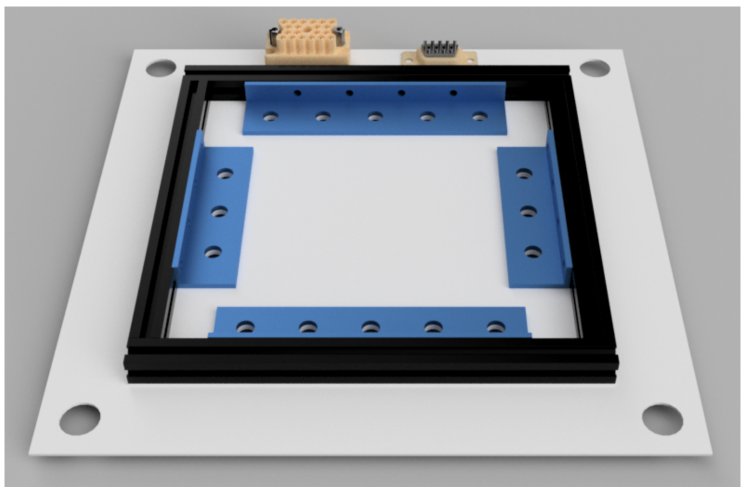

Figure 8: Payload mount. See figure 20 for dimensional drawing

1.5 Electrical Design

Sensors:

HASP's main avionics board will be a Raspberry Pi Zero. The neutron detector will be used to detect neutrons in a specific range of energies, the hygrometer will detect humidity and temperature, and the heater will ensure that all systems stay in a specific temperature range.

Sensor Interface:

H.A.R.T.'s designed circuit board will transform the power and connect all of the instruments together. The H.A.R.T. Board will interface with all of the instruments via molex connectors. The main avionics system will have a connection to the gondola via a DB9 connector which will allow communications between the devices. There will be four serial connections, one going to each of the subsystems.

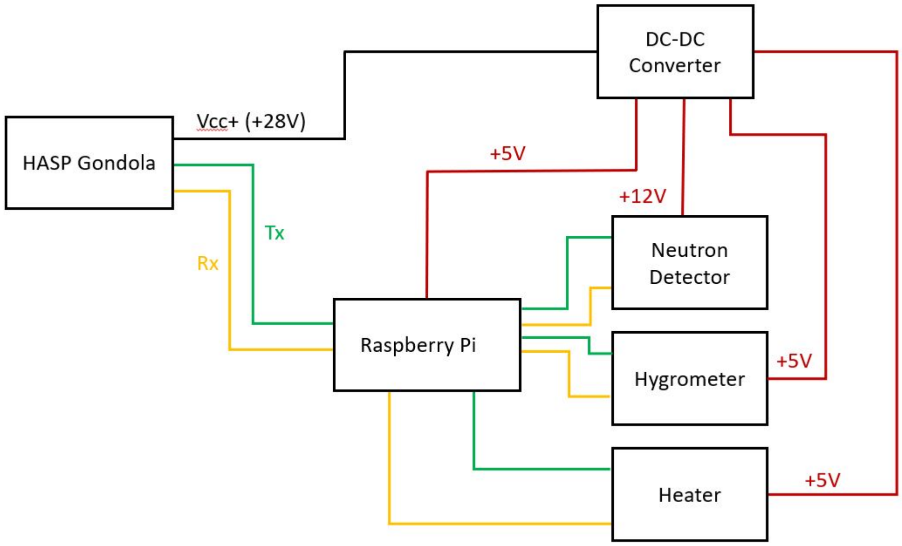

Figure 9: Payload Integration

Controllers:

HART will utilize a Raspberry Pi Zero computer as a controller. The HASP flight system will communicate with the Raspberry Pi Zero using an RS232 serial communication standard, 8 data bits, no parity, 1 stop bit, no flow control settings, along with serial port speeds of 1200 baud. The RS232 cannot communicate directly to the Raspberry Pi Zero and so a logic level converter will be used to assist its operation at lower voltage levels, allowing for communication. The Raspberry Pi Zero will communicate with the neutron detector, hygrometer, and heater, collecting data from each and keeping track of the health of the system. Even though the Raspberry Pi will interconnect the entire payload, control systems for each of the subsystems will also be implemented, due to the limited communication to the payload. The neutron detector will operate as a control system, in case it reaches low temperatures, turning on for 20 minutes and off for 10 minutes. The hygrometer will operate as a control system, as it will be turned on and off based on altitude, due to water saturation. The heater will only be turned on while the detector is not running, unless the temperature becomes extremely low. This will adjust the other control systems to be on standby if the temperature is too low.

Data Acquisition:

The Mini-NS is responsible for recording events that take place throughout the flight. When a gamma ray of neutron passes through the CLYC sensor head, a flash of light occurs as it reacts with the crystal structure, leaving a fluorescence behind. This fluorescence decays within a fraction of a second (usually within nanoseconds the light fades). This pulse of light is then routed into photomultiplier tubes that amplify the signal so that the result can be distinguished and then fed into the FPGA, which interprets the results of the light decay pattern and the recorded energy value that the event had. The ratio of these light interactions is known as PSD or Pulse Shape Discrimiation. With this, and the corresponding energy value, a data point can be established. From previous experiments, (most noticeably the LunaH-Map mission) neutron interactions tend to fall into the PSD ratio of 0.2-0.4 and have an energy value in the 2000-4000 keV range. Gamma rays make up a much larger portion of the recorded data, but are not the primary observational target for this experiment and can therefore be discarded as unwanted data. The FPGAs installed firmware allows a window of observation to be set, and we plan to set this window to observe only neutrons that fall in the parameters listed above. The communication to the Mini-NS is handled via RS-422, which will be connected to a circuit board that will accommodate the +/- 6 VDC and step down the voltage to 3 VDC to allow communication with the main control compute module.

The Phymetrix Loop-powered Moisture Analyzer model PLMa, or hygrometer, takes in air which goes into the nanopore sensor, and analyzes the relative humidity content through a voltage reading. The hygrometer will measure water moisture on gasses in the -110 Cdp to 20 Cdp range, while operating in the power range of 5 VDC to 28 VDC, and drawing 4-20 mA. A HART interface (Highway Addressable Remote Transducer) is included, overlaying signals on the 4-20 mA loop current (Phymetrix, 2013). Therefore, it will respond to any of the HART Universal commands. The instrument is equipped with an M12 connector and is able to connect an RS-232 serial port. The Raspberry Pi Zero will be connected to a ADS7886S-BDCKR analog to digital converter which will be connected to the hygrometer. We will then measure the current with a sensing resistor Rs to find the absolute humidity measurement, or the PLMa Measured Value, based on the following equation from (Phymetrix, 2013):

$$\text{PLMa Measured Value} = \text{L} + \left(\frac{\left(\left(\frac{\text{V}_{\text{sense}} \text{ x } 1000}{\text{R}_{\text{sense}}} \right) - 4 \right) \text{x } (\text{H} - \text{L})}{16} \right)$$

Where:

H = PV output Upper Range as set by HART command #35, read by #15
L = PV output Lower Range as set by HART command #35, read by #15
V_{sense} = Voltage sensed by the PLMa
R_{sense} = Resistance sensed by the PLMa

Storage:

The HART team has been allocated two detector modules each with 64 GB (32 GB * 2 cards) micro SD cards. Once events have been recorded and formatted automatically by the system, the data is stored onboard and will be accessed at a later time after the conclusion of the flight.

Telemetry:

The expected telemetry that the HART team will receive is the statement of health along with the latest recording of events from the Mini-NS, the latest moisture analysis from the PLMa, and finally the temperature of both CLYC sensor head and PLMa to ensure the equipment is kept within the recommended operational range.

Power Supply System:

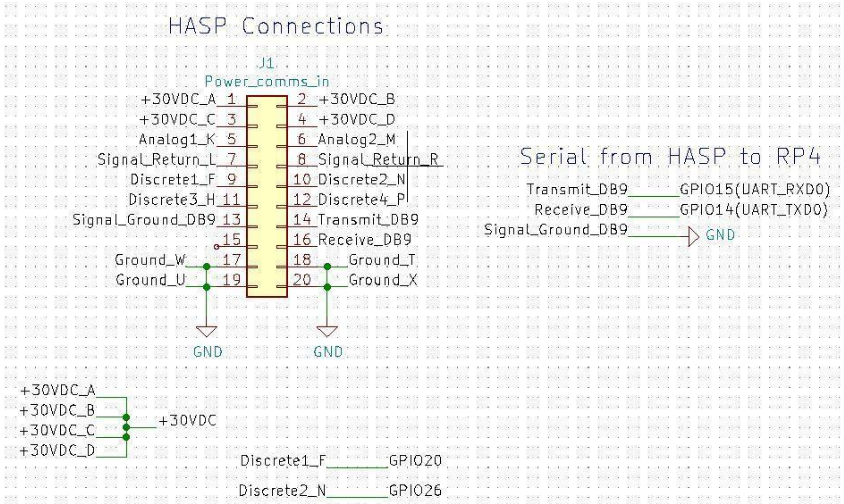

Figure 10: EDAC to HART Connections

Our power supply system begins with the 29-32 VDC supply from the Hasp Gondola that is fed into the H.A.R.T. Board, where it runs into two DC - DC Converters. The first converter takes the 29-32 VDC and drops it to 12 VDC. The second converter takes the 12 VDC and drops it to 5 VDC. The 12 V will be used to supply the neutron detector and the heater, while the 5 V will be used to power the avionics computer and hygrometer. The gondola uses an EDAC 516-020 for power, which is connected to the board via a Molex connector and will be used to connect all of the instruments.

1.6 Thermal Control Plan

The payload will survive in a temperature range of -45 °C to 85 °C, the expected range being beyond the limits of operation at -65 °C to 30 °C. The CYCL sensor heads, FPGA, and PLMa will need to be heated in order to maintain coherent operation and ensure clean data. The payload will also be painted entirely white in order to reflect as much incoming radiation from the sun as possible. Paints will be tested in order to determine the best possible reflective coating for the payload.

If a lack of heat in the payload is the primary concern, one of the following plans to contain said heat will be implemented:

Option 1: PTC (Positive Temperature Coefficient) heaters are thin, flat and flexible, averaging 75 µm in thickness. They draw low amounts of energy and can be screen printed to accommodate various shapes and sizes. This can be applied to both the sensor heads and the hygrometer.

Option 2: Passive heating. The thickness of the shielding (polyethylene) will be between 25.4 mm to 38.1 mm. The survivability of the sensor heads have been rated down to -25 °C with temperature fluxes of +/- 10 °C per minute.

Option 3: The heat of various components such as the FPGA (Field Programmable Gate Array) and the computer board could conceivably be used as a source to heat the detector and hygrometer. This would effectively turn the sensor heads and hygrometer into heat sinks.

If too much heat trapped in the payload is the primary concern, one of the following plans to disperse the heat build up will be implemented:

Option 1: A thin sheet of either copper or aluminum that follows one of the faces of the sensor heads, will then be affixed to the adjoining face of the payload.
Option 2: A thin wire could also be attached to the hygrometer, which is connected to one of the internal faces of the payload.

2. Team Structure and Management

2.1 Team Organization and Roles

Name	**Email**	**Phone number**	**Roles & Responsibility**
Aaron Geels	ageels@asu.edu	(480) 313-5924	Housing/Mechanical
Adrianna Matthews	anmatth2@asu.edu	(480) 266-2472	Hygrometer/Thermometer
Alice Kaine	akaine@asu.edu	(928) 533-6397	System
Eliana Benites	embenit2@asu.edu	(602) 541-9131	Science
Jonathan Greenfield	jdgreenf@asu.edu	(602) 500-9286	Integration
Jonathan Vazquez	javazqu3@asu.edu	(602) 435-0074	Software
Justin Lefebvre	jtlefebv@asu.edu	(480) 434-8073	Detector
Leon Dilly	mdilly@asu.edu	(928) 499-0075	Ground Data
Christopher Groppi	cgroppi@asu.edu	(480) 965-6436	Instructor
Craig Hardgrove	chardgro@asu.edu	(480) 727-2170	Advisor

Figure 10: HASP team contact information

2.2 Timeline and Milestones

Milestone	**Date**	**Status**
SRR	13 October 2021	Passed w/ RFAs
PDR	10 November 2021	Passed
CDR	6 December 2021	Passed
Application Review	6 December 2021	In Progress
Application Submission	7 January 2021	TBD

SIR	TBD	TBD
ORR	TBD	TBD
PFAR	12 September 2022	TBD

Figure 11: HART Timeline. Use with Figures 12 -14

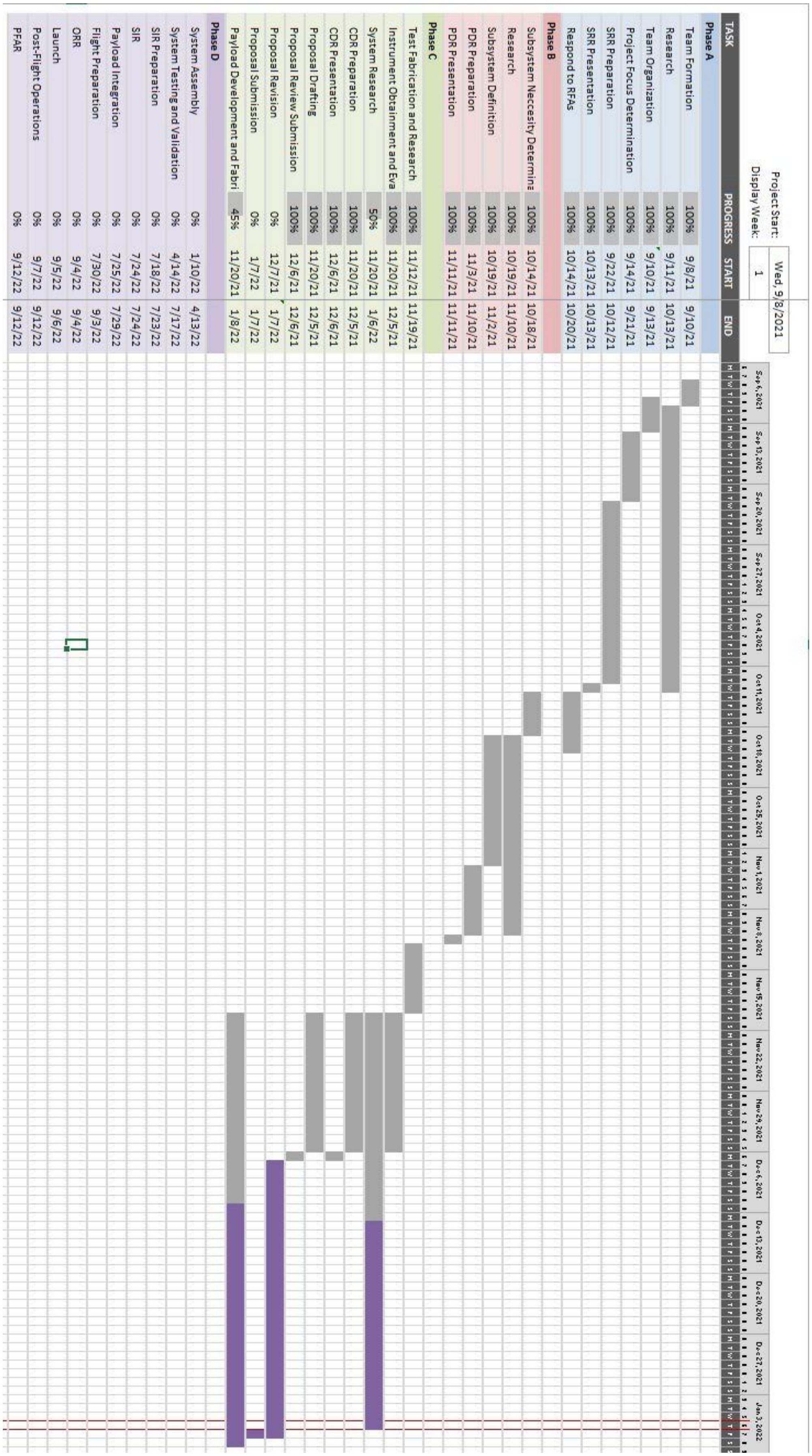

Figure 12: Gantt Chart Part 1.

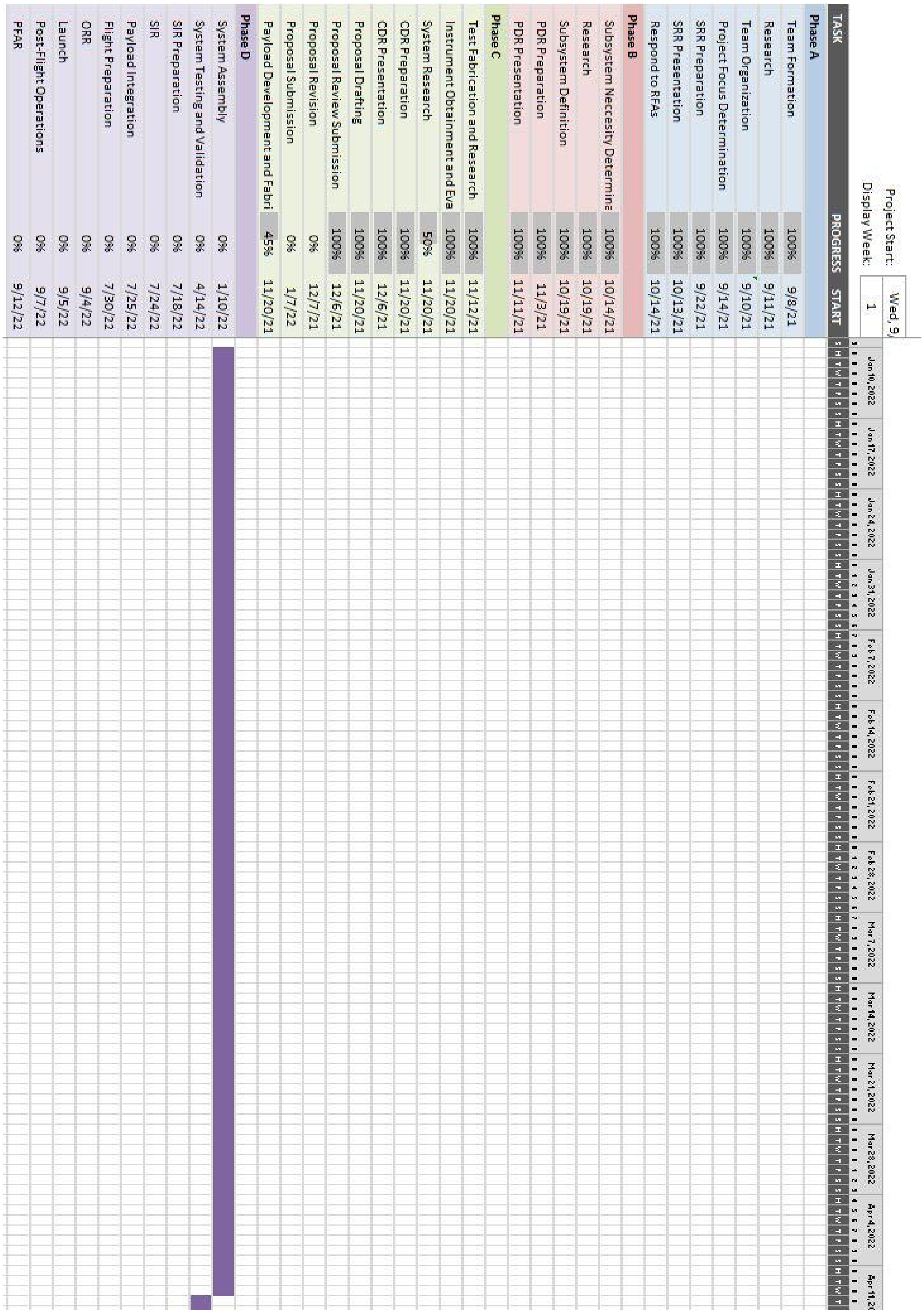

Figure 13: Gantt Chart Part 2

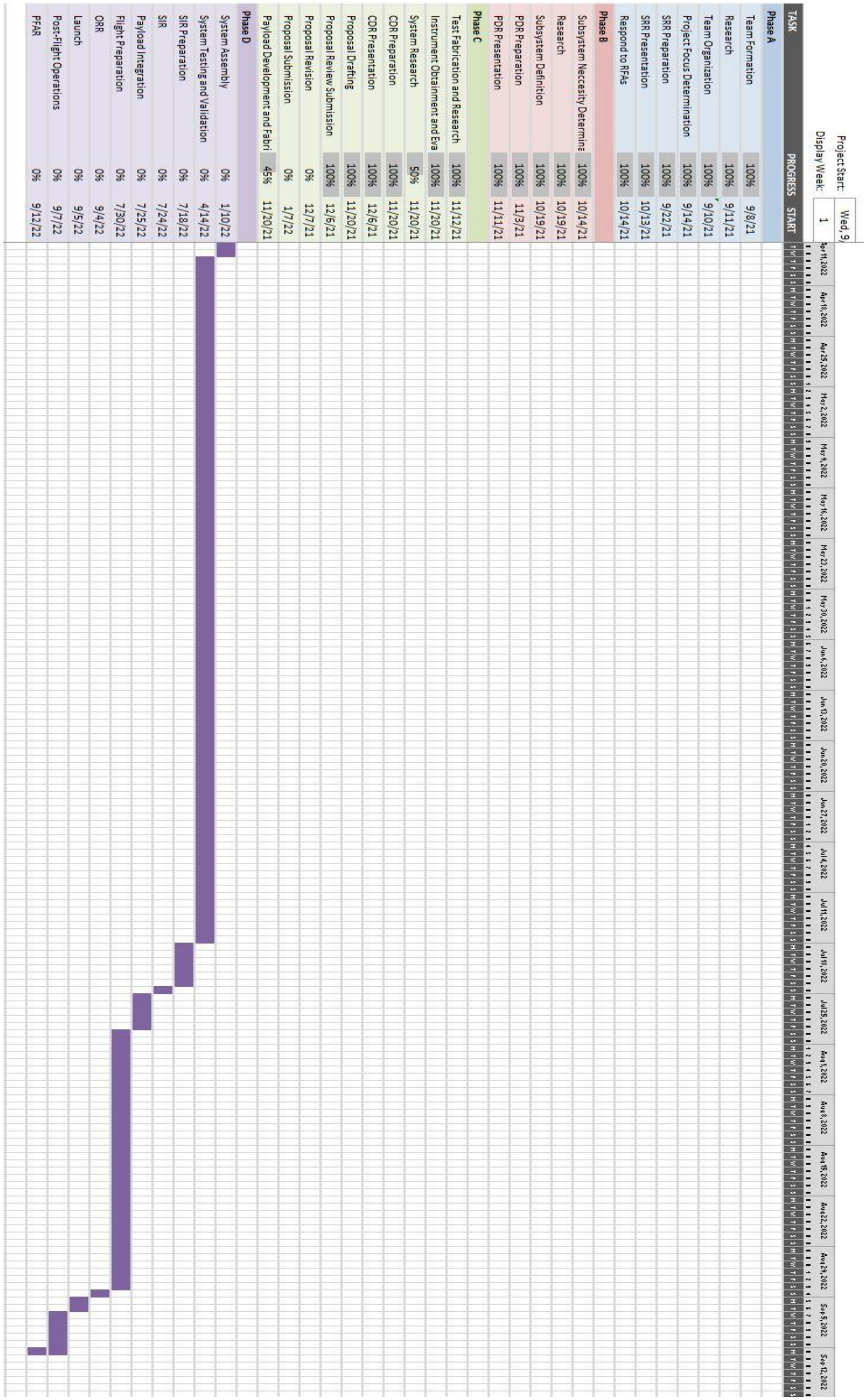

Figure 14: Gantt Chart Part 3

2.3 Anticipated Participation in Integration and Launch operations

The HASP team's integration plans will be available via a google document throughout the duration of the project. We plan to test serial communications between the Raspberry Pi and HASP using the RS232 protocol. ASU's thermo vac chambers will be utilized to ensure the readiness of all systems prior to integration. We will simulate 10 g vertical and 5 g horizontal shock to verify a robust structure. Upon the successful completion of our testing and integration procedures we will bring our payload to Palestine, TX for HASP integration.

The serial connection between HASP and the Raspberry Pi Zero will be secured quickly to prevent any major issues during the flight. Due to the RS232 using a different logic level, we will need a bi-directional logic level shifter. Once the logic level shifters are complete, numerous tests will be performed to ensure their compatibility with our system for the entire flight. The Raspberry Pi uses 3.3 V logic and if it receives anything much higher it will burn out, rendering it useless.

There are a few thermo vacs at ASU that HASP can use to verify that our systems will be unaffected. Since the air is very thin at altitude, our systems do not radiate to dissipate heat, so we need to ensure our circuitry will survive those conditions prior to taking the payload to Texas for integration. Most of the chips on our circuit board have already been tested in similar conditions, but we will verify that all is working properly.

We plan to conduct vertical and horizontal testing to guarantee our payload remains attached to the mounting plate that HASP provides. This may include some drop testing that will simulate the vertical stresses that could be present at launch during the mission. Similar tests will be conducted to verify that horizontal stress will not affect the payload.

Once all tests have been completed and all components are operating nominally, a minimum of one team member will transport the payload to Palestine, TX. The team member will bring all of the procedural documents and spare items of each main component to ensure necessary replacement parts are available.

For launch operations, the HASP team will utilize a preprepared google document which will be updated weekly to make sure all procedures have stayed the same. This includes a detailed step by step setup procedure for each subsystem, incorporating pictures and diagrams. The goal is to thoroughly explain assembly, integration, and power cycling to ensure the procedure can be replicated in the future. We also require at least one team member to accompany the payload to Fort Sumner, New Mexico.

3. Payload Interface Specifications

3.1 Weight Budget

HASP's weight budget includes all major components as well as the structure itself. Miscellaneous small items such as the screws, cables, possible heaters, and mounting structures are currently grouped together in an estimated mass of 200 g. Our design has not been fully fleshed out enough to know for certain what the mass will be. Not including these miscellaneous items, our total mass estimate is 1.5 kg. This leaves plenty of room for error within the 3 kg mass budget, in the case that our miscellaneous section exceeds the estimate, even with the upper uncertainty. Many of our components have their own documentation with listed weights, aside from the Mini-NS Board, which needs to be weighed.

Item	Mass	Uncertainty	Comments
Mini-NS Board	15 g	5 g	Estimated
Sensor Head (x2)	440 g (220 g each)		From documentation
Hygrometer	170 g		From documentation
Raspberry Pi	9 g		From documentation
Superstructure	860 g		From documentation
Misc (Screws, cables, etc.)	~200 g	~100 g	Estimated
TOTAL	~1700 g		

Figure 15: Weight table

3.2 Power Budget

The power budget is broken into two groups, the first including instruments that use 12 V and the second including those that use 5 V. Two DC - DC converters will be utilized, one that takes 9-36 VDC and transforms it into 12 VDC, and another that takes 10.8-13.2 VDC and transforms it into 5 V. During the flight, the instruments will be turned on and off, to ensure they do not all run at the same time. This conserves processing power and electrical draw, while ensuring the allotted budget is accounted for throughout the flight, even when the gondola batteries reach their minimum.

The instruments that require 12 V are the neutron detector and heater. The neutron detector uses an estimated peak of 8 W or 12 V at 0.666 A. The heater uses an estimated peak of 3 W or 12 V at 0.25 A. The instruments that require 5 V are the Raspberry Pi Zero, which uses a peak 0.75 W or 5 V at 0.15 A, and the Hygrometer that uses a peak 0.1 W or 5 V at 0.02 A.

Therefore, we have an estimated maximum of 11 W at 12 V using 916 mA, and an estimated maximum of 0.85 W at 5 V using 170 mA.

While using the DC – DC converters the maximum draw must be accounted for, otherwise efficiency will be lost. Due to the system's power conservation, it will be easy to simulate expected power consumption, as seen in *Figure 16.* Due to the guarantee of a maximum of 28 VDC at 0.5 A or 14 W, this was used as the base. The 12 V converter will use the THN 30-2412 WIR, which is only 89% efficient and can provide up to 2500 mA. The 5 V converter will use the PDSE2-S12-S5-M-TR, is 83% efficient, and can provide up to 400 mA.

Due to the instruments being on at various times, a simulation was generated to determine power consumption. To provide an idea of the maximum draw, the minimum draw from each instrument was used to calculate maximum usage, as seen below:

14 W at 30 V => 89% => 12.46 W at 12 V => 83% => 10.34 W at 5 V

Neutron Detector (8 W at 12 V) + Heater (3 W at 12 V) = 11 W at 12 V
Raspberry Pi: 1 W at 5 V

(12.46 W at 12 V) - (11 W at 12 V) = (1.46 W at 12 V) => (1.46 x 0.83) = 1.21 W at 5 V
(1.21 W at 5 V) - (1 W at 5 V) = 0.21 W

The results conclude the maximum draw as the equivalent of 13.79 W (14 W - 0.21 W). Further simulations were constructed for a 12-hour time duration, given each instrument's maximum and minimum draw, which provided an average with error bars.

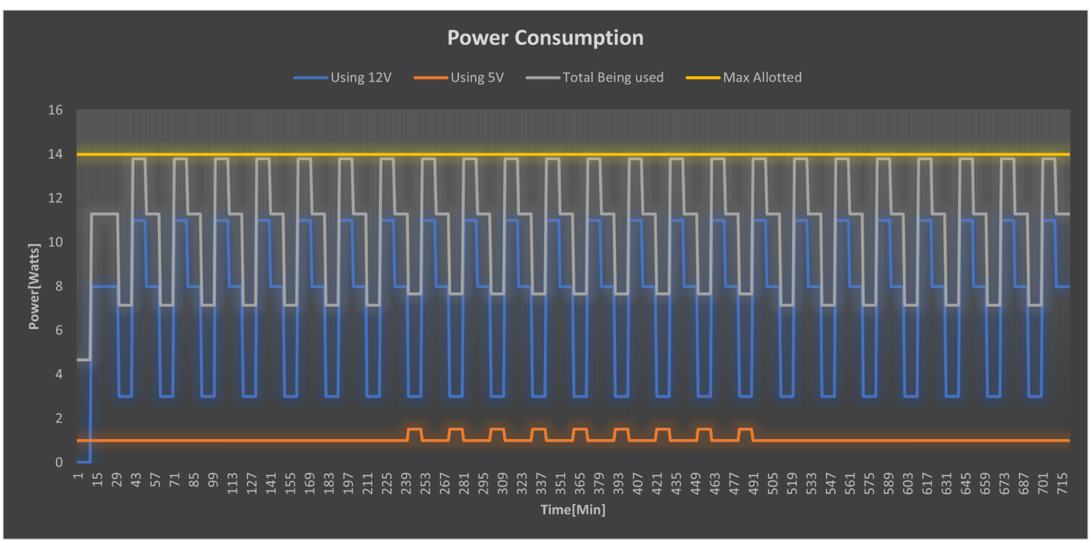

Figure 16: Simulation of power consumption vs time

Looking back at *Figure 16*, the absolute maximum draw still falls under the gondola's minimum supplied draw. Further, the instruments also fall under the converter's supplied amount. This indicates that the system used by HART is very robust and unlikely to fall victim to overcurrent.

Item	Voltage (V)	Current(A)	Power (W)	Comments
Detector	12	0.666	8	
Hygrometer	5	0.02	0.1	
Raspberry Pi Zero	5	0.2	1	
Heater	12	0.25	3	
TOTAL	34	1.136	12.1	

Figure 17: Power table

3.3 Downlink Serial Data

The HASP team is requesting to receive GPS time and location to help answer our science questions. The GPS time and location data will be collected every five seconds and downloaded via the serial connection from our payload to the HASP flight system. The data will provide geographical context to our atmosphere data to be compared with the data on the ground.

We will also be downlinking voltages and temperatures of critical components from the payload to the ground. The downlink data will ensure the payload is powered on and working properly. We will use a python serial communications library set up for 1200 baud, 8 data bits, no parity, 1 stop bit and no flow control. We will then transmit our data using a USB to serial connection and will interface with the HASP serial connection by wiring the DB9 pigtail as a NULL modem to our payload. The table and calculations below in *Figure 18* summarize what data will be telemetered down and the package size. For redundancy, we will be sending two copies of our data package every 60 seconds.

Byte	Bits	Description
1	0-7	Record Type Indicator
2-5	0-31	Timestamp (seconds since January 1, 1970)
6-7	0-15	Record Size
8	0-7	Checksum
9-23	0-111	NS-MIni Data

TBD	TBD	Hygrometer Data
TBD	TBD	Heater Temp

Figure 18: Telemetered data and package size

$$23\ bytes\ x\ \frac{8\ Bits}{1\ Byte}\ =\ 184\ bit\ package\ size$$

$$184\ bit\ package\ size\ x\ 2\ copies\ every\ minute\ =\ 368\ bits\ per\ minute$$

$$\frac{368\ bits}{1\ minute}\ x\ \frac{1\ minute}{60\ seconds}\ =\ 6.1\ bits\ per\ seconds$$

$$\frac{368\ bits}{1\ second}\ \text{x 20 minutes} = \text{7360 bits} = \text{.92 kbyte}$$

3.4 Uplink Serial Commanding

We do not anticipate utilizing any uplink commands.

3.5 Analog Downlink

We have decided to not use the analog downlink at all and will send all of our data over a serial port.

3.6 Discrete Commanding

HASP will not need any additional discrete commands.

3.7 Payload Location and Orientation Request

The position preference of the HART payload is not of great importance as long as the payload sits on the outer mounting rings of the HASP gondola. However, there is a preference as to the orientation of the payload. The exterior of the payload will have a marker to identify which face is to be pointed toward the ground. This face must be pointed in this direction to discriminate against surface and cosmic ray originating neutrons.

3.8 Special Requests

We have no special request.

4. Preliminary Drawings and Diagrams

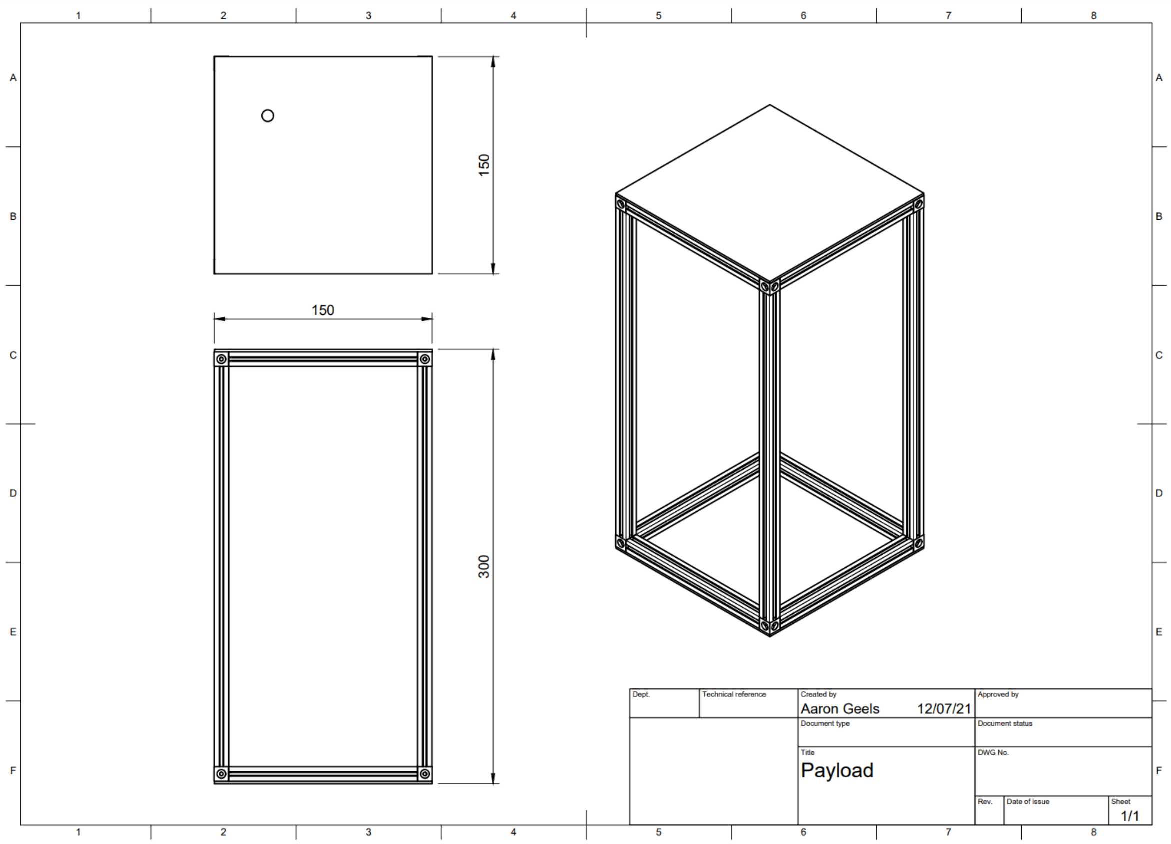

Figure 19: Payload box. Dimensions (150x150x300)mm

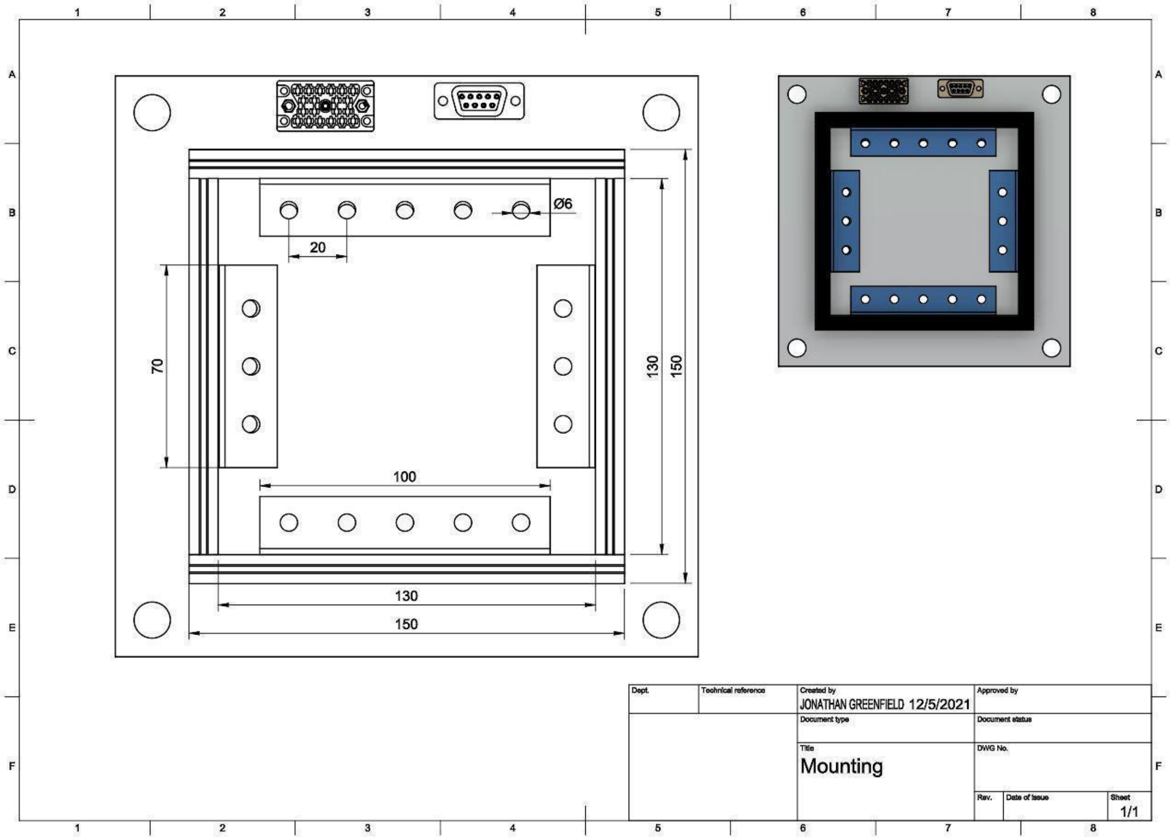

Figure 20: Payload mounting. Dimensions in mm

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Appendix A

Timeline and schedule have been drawn from dates provided by HASP and ASU faculty supervisor.

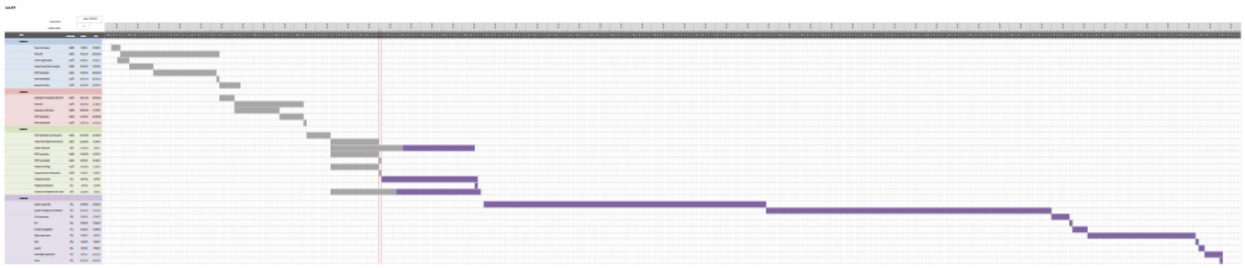

Figure 21: Timeline and Schedule. Use with Figure 21.

Milestone	Date	Status
SRR	13 October 2021	Passed w/ RFAs
PDR	10 November 2021	Passed
CDR	6 December 2021	Passed
Application Review	6 December 2021	In Progress
Application Submission	7 January 2021	TBD
SIR	TBD	TBD
ORR	TBD	TBD
PFAR	12 September 2022	TBD

Figure 22:Timeline and Schedule. Use with Figure 20.

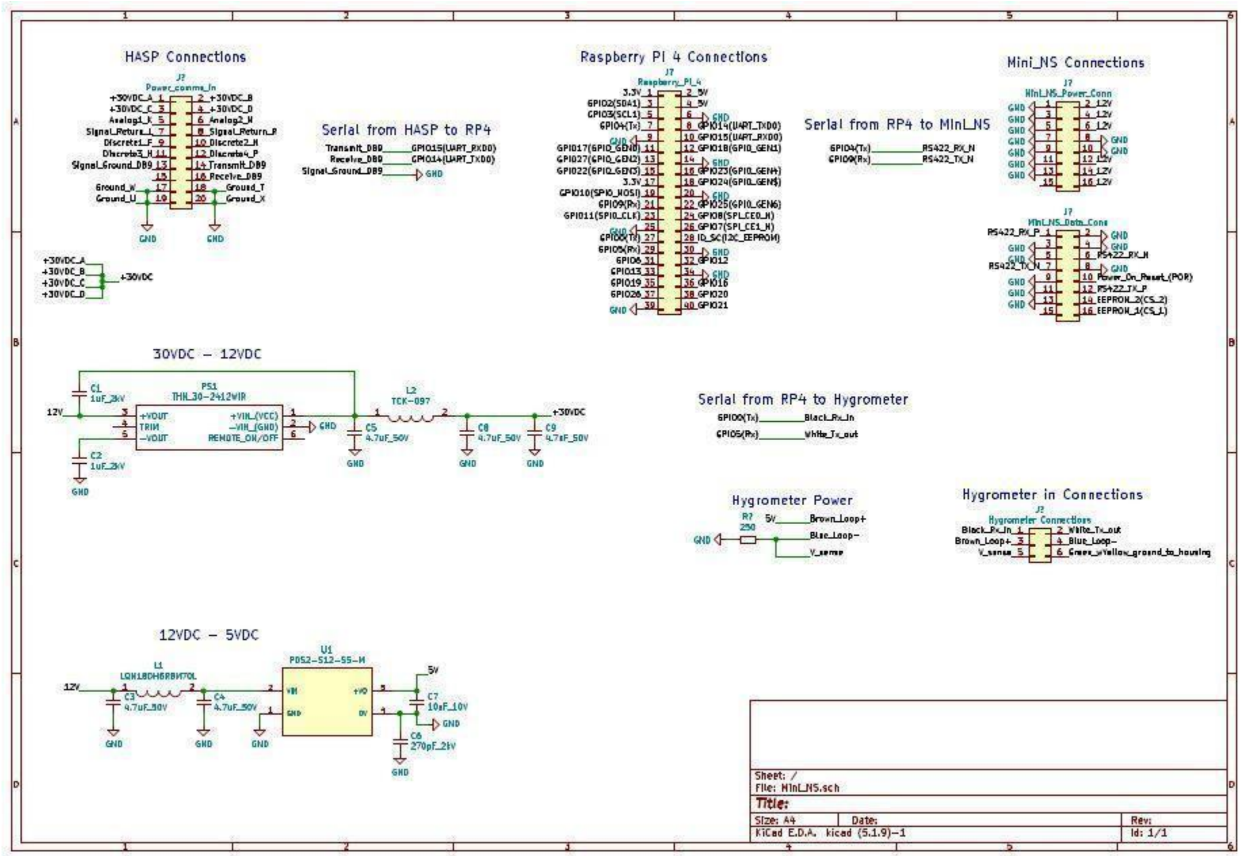

Figure 23: Schematic of PCB

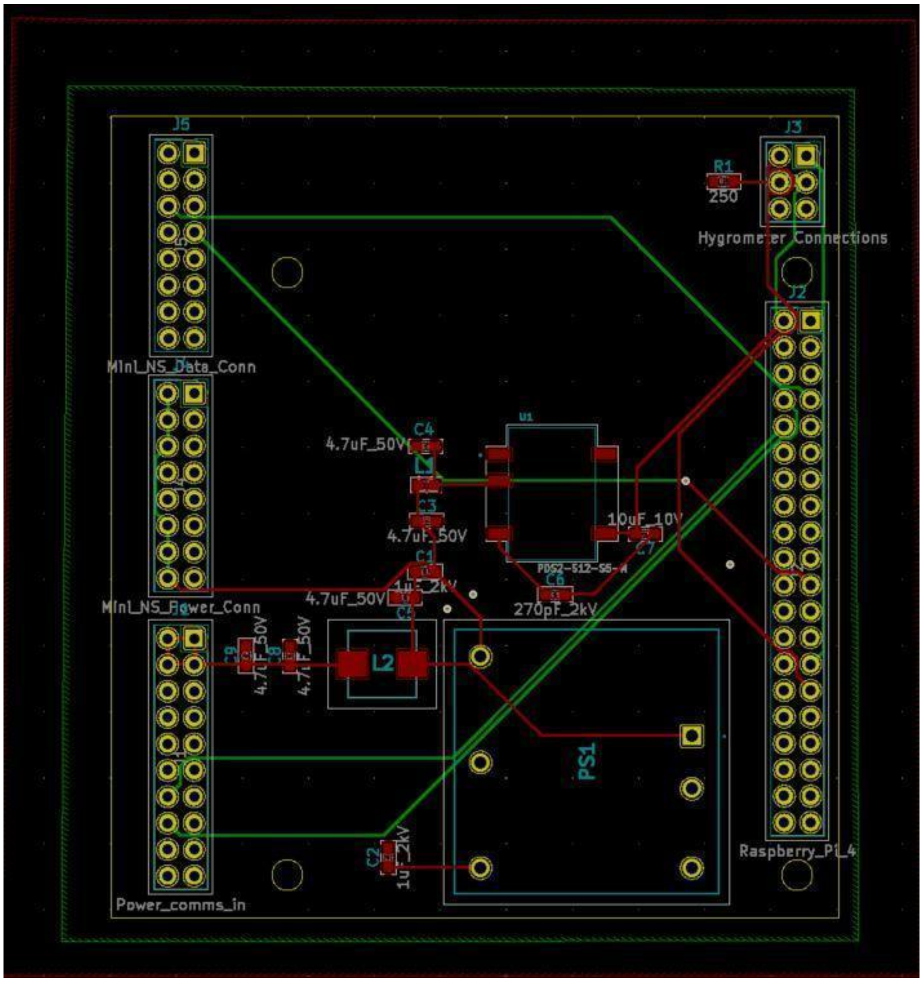

Figure 24: Preliminary PCB

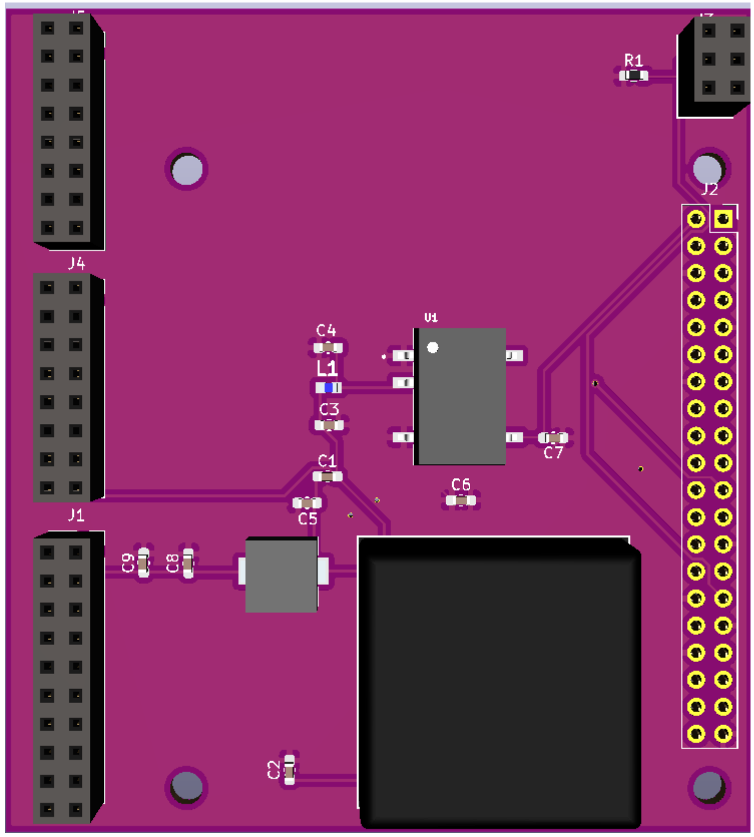

Figure 25: Front side of the H.A.R.T. Board

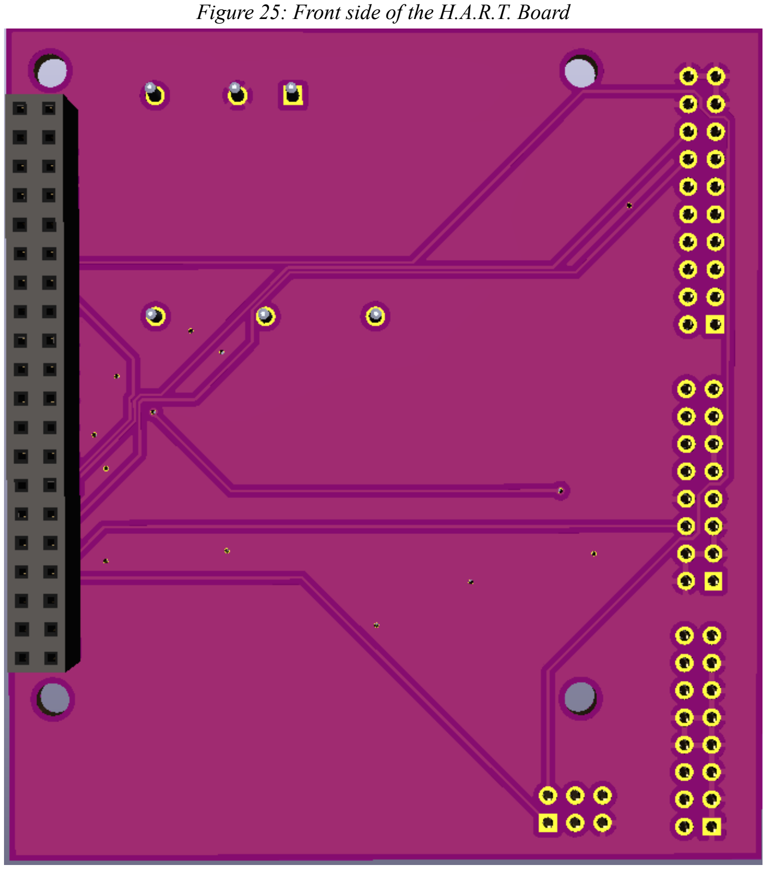

Figure 26: Back side of the H.A.R.T. Board

Appendix B: NASA Hazard Tables

Appendix B.1 Radio Frequency Transmitter Hazard Documentation

HASP 2022 RF System Documentation	
Manufacture Model	N/A
Part Number	N/A
Ground or Flight Transmitter	N/A
Type of Emission	N/A
Transmit Frequency (MHz)	N/A
Receive Frequency (MHz)	N/A
Antenna Type	N/A
Gain (dBi)	N/A
Peak Radiated Power (Watts)	N/A
Average Radiated Power (Watts)	N/A

Appendix B.2 High Voltage Hazard Documentation

HASP 2022 High Voltage System Documentation	
Manufacture Model	N/A
Part Number	N/A
Location of Voltage Source	N/A
Fully Enclosed (Yes/No)	N/A
Is High Voltage source Potted?	N/A
Output Voltage	N/A
Power (W)	N/A

Peak Current (A)	N/A
Run Current (A)	N/A

Appendix B.3 Laser Hazard Documentation

HASP 2022 Laser Hazard Documentation			
Manufacture Model		N/A	
Part Number		N/A	
Serial Number		N/A	
GDFC ECN Number		N/A	
Laser Medium		N/A	
Wave Type		*(Continuous Wave, Single Pulsed, Multiple Pulsed)*	
Interlocks		*(None, Fallible, Fail-Safe)*	
Beam Shape		*(Circular, Elliptical, Rectangular)*	
Beam Diameter (mm)		**Beam Divergence (mrad)**	
Diameter at Waist (mm)		**Aperture to Waist Divergence (cm)**	
Major Axis Dimension (mm)		**Major Divergence (mrad)**	
Minor Axis Dimension (mm)		**Minor Divergence (mrad)**	
Pulse Width (sec)		**PRF (Hz)**	
Energy (Joules)		**Average Power (W)**	
Gaussian Coupled (e-1, e-2)		*(e-1, e-2)*	
Single Mode Fiber Diameter		N/A	
Multi-Mode Fiber Numerical Aperture (NA)		N/A	

Appendix B.4 Pressure Vessel Hazard Documentation

HASP 2022 Pressure Vessel Documentation	
Description	
Maximum Operating Pressure (PSIG)	N/A

Fluids (GN2, Air, etc)	N/A

Appendix B.5 Battery Hazard Documentation

HASP 2022 Battery Hazard Documentation	
Battery Manufacturer	N/A
Battery Type	N/A
Chemical Makeup	N/A
Battery modifications	*(Must be NO)*
UL Certification for Li-Ion	N/A