HASP Student Payload Application for 2016

Payload Title:
Correlation Of Atmospheric Terrestrial gamma flashes and Lightning (COATL)

Payload Class: (check one)	Institution:	Submit Date:
☐ Small ☒ Large	Louisiana State University	12/18/15

Project Abstract

High energy gamma ray flashes from terrestrial sources have been observed by NASA satellites for decades, but the actual mechanism, assumed to be thunderstorm lightning, has yet to be fully characterized. In order to determine how TGF emissions are related to lightning, conditions within thunderstorms that might lead to TGF emissions must be characterized. This can be accomplished by using a small network of balloon-borne payloads suspended in and around thunderstorms that would detect, timestamp and measure the intensity of localized electric fields, gamma radiation bursts, and lightning strikes. The goal of COATL is to test the effectiveness and performance of the before mentioned payloads in a high altitude environment. In order to simulate a network of multiple payloads in flight, four identical payload boxes will be constructed and will all fly together on one large payload platform. The payloads will all collect data and communicate with one another as if they were on separate balloons in a thunderstorm.

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Correlation of Atmospheric Terrestrial gamma flashes and Lightning (COATL)

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December 18, 2015

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1.0 Payload Background and Objectives

The purpose COATL is to test the systems of the 2015 USIP COTEL payload in atmospheric conditions before launching into thunderstorms for the final phase of the mission. This mission will test the communications, data storage, TGF detection, and lightning detection subsystems of COTEL as subsystem tests while also gathering data on TGF relations with lightning events from high atmospheric elevations on the HASP platform.

1.1 Scientific Background

The first documented detection of a Terrestrial Gamma Flash (TGF) was in 1994 by the Burst and Transient Source Experiment (BATSE) (Fishman, 1994). Much of the known information about TGFs is from on-going experiments in Earth-orbit such as BATSE, the Reuven Ramaty High Energy Solar Spectroscope Imager (RHESSI), Astro-Rivelatore Gamma a Immagini Leggero Experiment (AGILE), and the Fermi Gamma Ray Telescope (Smith, 2005; Tavani, 2010; Briggs, 2010). Ground-based TGF detection experiments, such as the TGF and Energetic Thunderstorm Rooftop Array (TETRA) and TETRA II at Louisiana State University, have also been shedding light on the phenomenon (Ringuette, 2013).

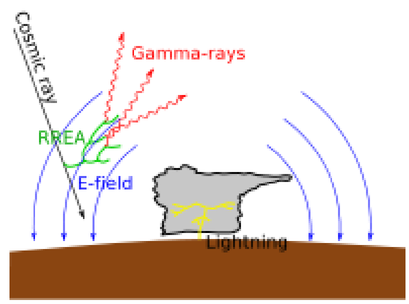


Figure 1: Diagram of a TGF production mechanism.

TGF events have been correlated with thunderstorm and lightning activity (Inan, 1996). For this reason, the current model of TGF production associates intense electric fields and high-energy electrons resulting from lightning strikes (**Figure 2.1**). Electrons accelerated to relativistic speeds by interaction with a cosmic ray initiate Relativistic Runaway Electron Avalanche (RREA). In RREA, this "seed" electron sets off a cascade of other electrons travelling at relativistic speeds. The electrons are accelerated by the intense electric fields within the storm. Gamma rays are produced when these electrons are deflected by air atoms in a process called Bremsstrahlung, or "breaking radiation" (**Figure 2.2**). When the electrons approach the positively charged nuclei of a given air molecule, the Coulombic force pushes the electron away. By the conservation of energy, the loss in kinetic energy of the electron appears as an emitted photon. Due to the high speeds of the electrons, these emitted photons can occur in the gamma-ray spectrum.

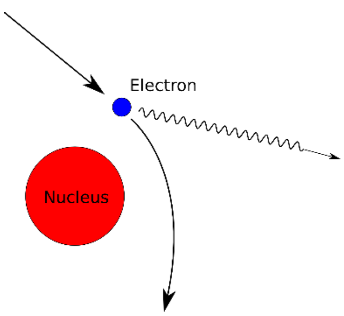


Figure 2: Diagram of gamma-ray emission from Bremsstrahlung.

TGFs are short-lived (< 1ms) and vary in energy (keV to MeV) (Ringuette, 2013). Recent data suggest that TGF-producing thunderstorms occur mostly in tropical regions throughout the spring and fall seasons during the afternoon and night (**Figure 2.3**) (Smith, 2005).

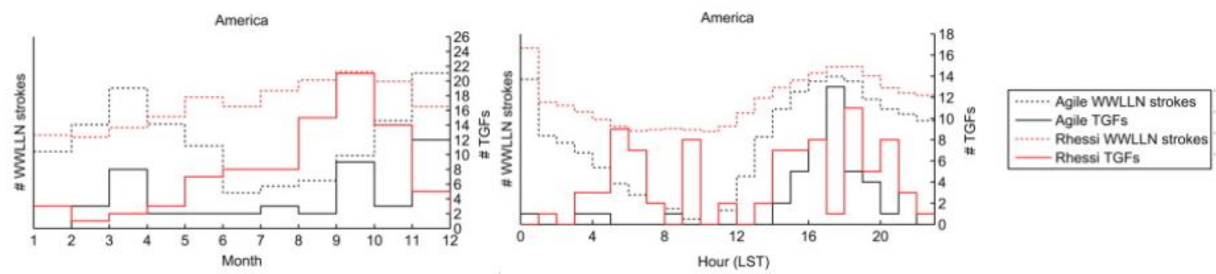


Figure 3: TGF Production Cycles shows the recorded TGFs and lightning strikes measured over the American tropics by AGILE and RHESSI for March 2009 – July 2012 distributed by month and diurnal time (Fabró, Ferran).

Lightning in Earth's atmosphere is produced when electrically charged regions of a cloud are equalized in a powerful electrostatic release. Preceding a lightning strike, thin channels of partially ionized gases called leaders extend from positively and negatively charged regions. When a negative leader and a positive leader connect, they act as a low-resistance path for the equalization of the electric potential. This produces a massive electrical discharge known as the return stroke. The return stroke lasts for an average of 30 microseconds and usually results in lightning bolts ranging from 5 - 20 kA. The bolt superheats the leaders causing the formation of a plasma channel. It takes hundreds of milliseconds for the plasma channel to dissipate. During this time, more strokes can occur along the existing plasma channel. These subsequent strokes are less powerful than the original return stroke and, while they do occur along the same plasma channel, they usually occur in a slightly different location due to the plasma channel being offset by wind. A single lightning strike is usually made of three or four of these individual strokes but can be comprised of as many as thirty strokes.

All types of lightning strikes emit broadband electromagnetic pulses known as sferics. These sferics are easily detectible through the use of an AM radio receiver, providing a timestamp and distance from the detector for each lightning event. There are also many lightning detection networks that make their data accessible. These networks include: the System de Surveillance et d'Akerte Foundre Par Interferometric Radioelectrique (SAFIR); from Earth Network's Weather Bug Total Lightning Network (WTLN); the Global Lightning Detection Network (GLD360); and Vaisala's National Lightning Detection Network.

1.2 Expected Results

COTEL expects to record the spatial and temporal position of lightning strikes, TGF events, and the electric fields. When a lightning strike is detected, measurements should be received showing both a large fluctuation in the electric field and a TGF event. Baton Rouge has 2 – 4 lightning strikes per kilometer squared per month and an average of 8 thunderstorms per month, with the average diameter of a thunderstorm being 16 km (Ringuette, 2013; Burt, Christopher C.; "Thunderstorm Basics"). Accounting for the attenuation of gamma photons through the atmosphere and the efficiency of COTEL's TGF detection system (> 73%), COTEL will be able to detect a TGF event from ~7 km away (**Figure 2.5**). With a thunderstorm diameter of 16 km and a detection radius of 7 km, COTEL will be able to detect TGF's across the entire area of a thunderstorm using several balloon borne payloads. Through the correlation of these measurements, as well as information from ground stations such as TETRA, radar weather maps, and lightning detection networks, COTEL shall create a comprehensive map of thunderstorm activity.

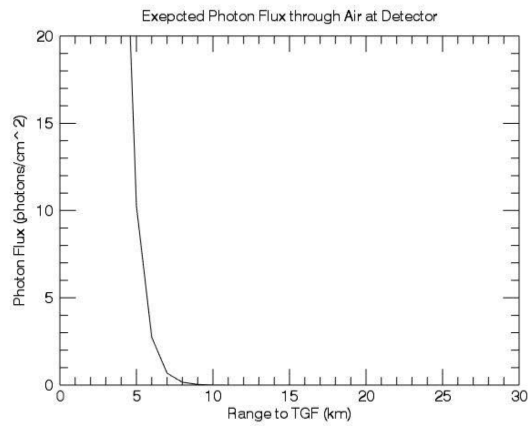


Figure 4

Simulation of the expected photon flux as a function of horizontal distance between the TGF source and detector. Simulation parameters: TGF event altitude is 15 km, Detector altitude is 20 km; ~10^18 photons emitted at TGF origin; and a mean energy of 0.5 MeV. Simulation code provided by Mansell, 2015.

Each sub-payload will save the backup data from the other payloads, while also collecting data on TGF's and lightning strikes.

1.3 Mission Traceability

The goal of COATL is to correlate TGF's and lightning strikes while also performing flight a flight systems test for the payload for later use in thunderstorms. Running multiple sub-payloads will test the inter-payload communications, which will transfer and save each sub-payload's data on each of the other sub-payloads. This is a key component of COTEL, which in the event of losing a payload in a thunderstorm, would still have the data saved to the other payloads.

Mission traceability is shown in a chart in the appendices.

2.0 Payload Design

2.1 High Level System Design

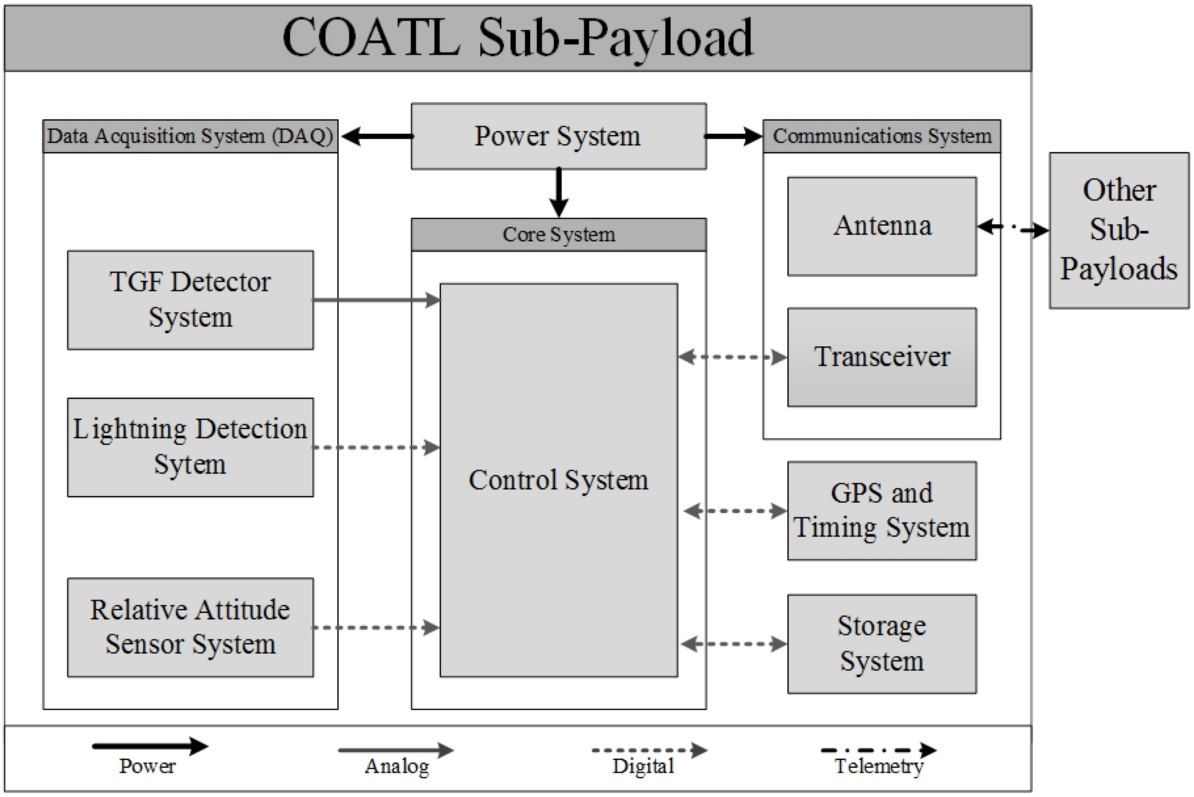


Figure 5: High Level System Design for each Sub-Payload

Each COATL sub-payload shall contain the core control, power, storage, data acquisition (DAQ), communication, and Global Positioning System (GPS) (for timing and position) subsystems. The DAQ consists of the TGF, lightning, and relative attitude detector subsystems. Data from all sensor subsystems will be accurately timestamped (using the payload's GPS disciplined clock) and recorded on-board each payload. The data will also be shared between payloads via the radio frequency (RF) payload network.

2.2 Electrical Design

The HUB contains the payload's primary flight computer, onboard storage, communication line to the HASP interface, and communication lines to each sub-payload. The HUB will provide power to each of the sub-payloads. Each sub-payload will contain a flight computer, a GPS device, a RF communication system, a TGF detector, a lightning detector, and a relative attitude sensor. Each sub-payload will also contain its own power regulation for its components.

Flight Computers

The COATL Flight Computers will consist of five Raspberry Pi 2 microcontrollers. One Pi 2 will be designated the primary (HUB) controller while the other four controllers will be secondary controllers. The hierarchy allows for complete control over the entire system while simultaneously allowing each sub-payload to operate independently. The secondary controllers will also communicate with each other through telecommunication.

The HUB controller will be responsible for:

- System Monitoring
- System Error Detection
- Monitoring environmental data
- Communicating with the HASP interface
- Communicating with the secondary controllers
- Executing uplinked commands

Meanwhile, the secondary controllers will be responsible for:

- Measuring and Recording TGF events
- Recording lightning events
- Measuring and Recording relative attitude
- Measuring and Recording environmental data
- Recording GPS data
- Broadcasting data to all other secondary controllers
- Receiving data from all other secondary controllers
- Communicating with the primary controller
- Executing commands from the primary controller

Pi 2 was chosen due to its multi-core processor that allows for the execution of multiple commands, Micro-SD card slot on the board, and low cost.

Onboard Storage

COATL will use multiple storage devices to record data events. Each controller will have its own micro-SD card. Every microcontroller will save its individual recorded scientific and environmental data as well as all received data from other sub-payload telecommunications.

Each data transmission will be in 47-byte data packets. A data transmission will occur once per minute. The packets will be saved onto onboard memory before being broadcasted to the other sub-payloads. For 15 hours of data collection at a rate of 47 bytes per transmission and 4 transmissions per minute (one per sub-payload), COATL will need roughly 170 kB of storage. This required capacity can be provided by a Micro-SD card.

HASP Serial Communications

A serial to RS232 converter will be used to communicate between the HUB controller and the HASP Interface. The HUB controller will downlink recorded data from each of the sub-payloads while waiting for uplinked commands from the HASP Interface.

Primary/Secondary Controller Serial Communications

The HUB controller will communicate with the secondary controllers through the use of multiple I2C serial lines. The I2C lines will be used to transmit data between the primary controller and the secondary controllers. Each secondary controller will be given a unique index number to identify itself on the primary controller and in recorded data.

Power Source

COATL will have two sources of power: HASP and four +12 V battery packs, one for each sub-payload. The battery packs will power the sub-payloads for the first four hours of the flight to ensure the full system can operate on an independent power source for the estimated COTEL flight time in high altitude conditions. Onboard relays will switch the power after either the four hours elapse or the battery pack dies. All HUB electronics will be powered by HASP power for the entire duration of the HASP flight.

Power Regulation

COATL will use a series of voltage regulators to provide all the necessary power. A step-down regulator will be used to reduce the supplied 30 V to 12 V. This will be accomplished through a Delta Electronics V36SE12004NRFA switching regulator, shown below.

Figure 6: Delta Electronics V36SE12004NRFA Switching Regulator

A series of voltage regulators will be used to provide the necessary voltages for the payload electronics. Each sub-payload will be provided 12V by the main switching regulator and will be designed to convert the 12V to the voltages required for operation.

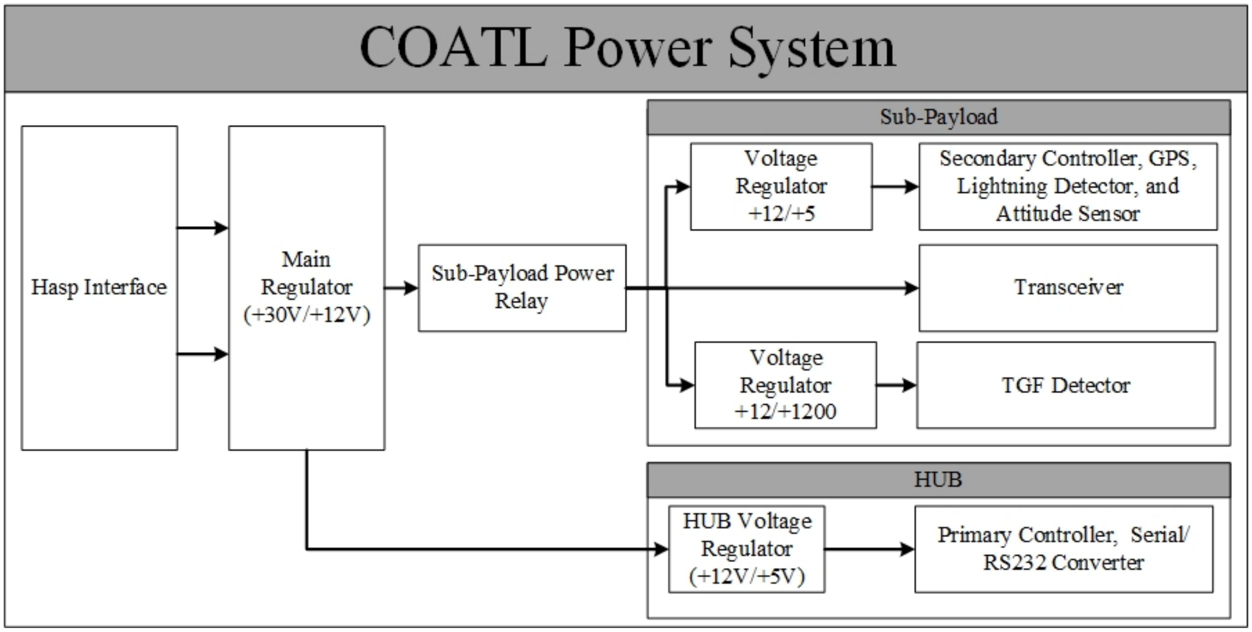


Figure 7: Power System Diagram

GPS and Timekeeping

COATL requires an accurate time keeping device to compare collected data to ground arrays and to accurately determine the position of TGF and lightning events. Clock resolution is determined by the number of crystal oscillations during a one second time frame and is adversely affected by temperature. This effect can be mitigated by an oven-controlled crystal oscillator (OCXO) coupled with a GPS one pulse-per-second (PPS) signal to discipline the system or a synchronized clock. The GPS receiver will also provide positioning information in addition to correcting the onboard clock.

RF Communications

The communication systems for the payload consists of each sub-payload having its own transceiver. These payloads operate on the 900MHz amateur band. This band was chosen because it allows for a large data rate while retaining excellent propagation characteristics in wet atmospheric conditions. The 900MHz band is also resistant to natural interference from lightning, and the antenna designs are compact. An externally mounted, full-sized 17cm dipole antenna with an anti-static coating will be used on each sub-payload. Each sub-payload shall also have a unique RF identifier and will communicate with Time Division Multiplexing as well as packets with checksum and error correction. The results will be recorded for the duration of the flight in order to verify inter-payload communication systems.

TGF Detector

TGF detection will be conducted by scintillation counting through a scintillator coupled to a photomultiplier tube (PMT) as shown in the figure below. The team is currently anticipating using BGO crystals as scintillators and photomultiplier tubes as light detectors.

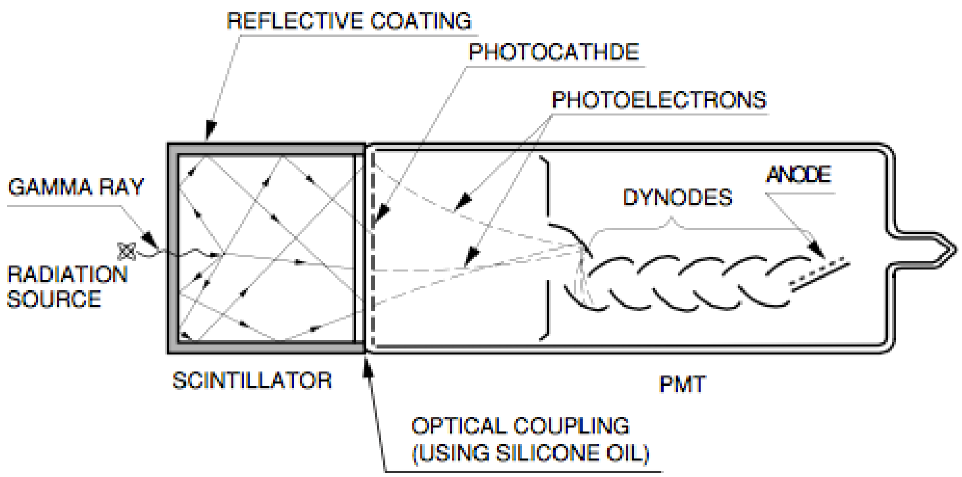


Figure 8: Scintillator and PMT coupling

By using scintillation counting method for detection of TGF occurrence through the entering of a BGO scintillator will produce a fluorescent flash. From this occurrence the PMT will output the relative pulse height (RPH) compared to a voltage impulse. Through operational use of scintillation counting to provide accurate radiation energy distributions by the output pulse height from PMT and the count rate to succeed our detection of TGFs.

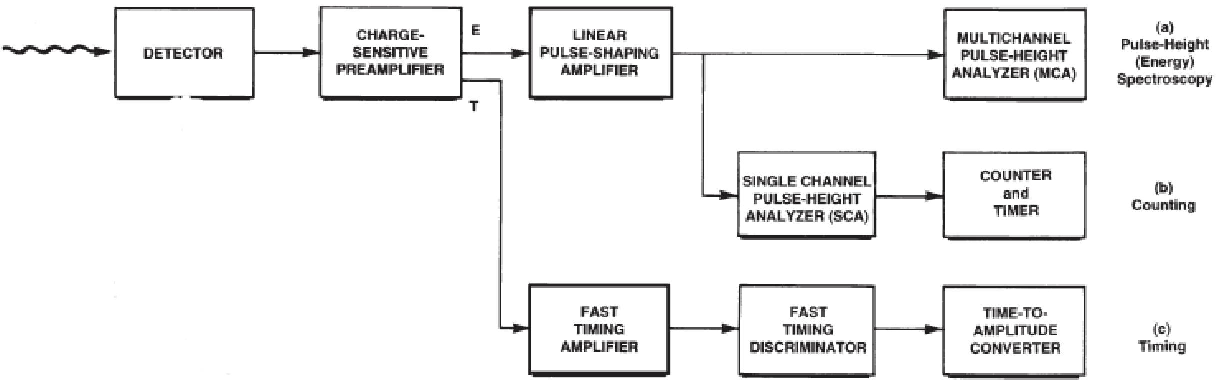


Figure 9: TGF Detector readout

Our sensor mechanism readouts of RPH from our PMT and scintillator coupling will also involve amplifying the signal for further shaping to achieve a readable analog signal. Including with the RPH detection we will need to include a counter that can measure how fast the RPHs are occurring.

Lightning Detection

Lightning detection is performed by an Amplitude Modulation (AM) receiver. The team is currently considering a RF Solutions QAM-RX5-433-ND AM Modulator connected to a small loop antenna to measure the sferics produced by lightning.

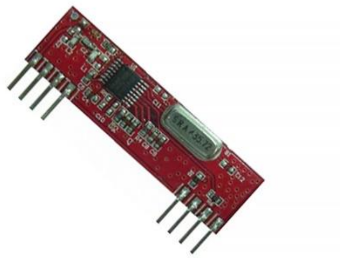


Figure 10: RF Solutions QAM-RX5-433-ND AM Modulator

The signal will be filtered to accommodate the 3 – 30kHz range that sferics usually occur on. More signal conditioning will be required in order to isolate the sferic waveform. The signal conditioning circuits will be designed and tested during the development phase of the project.

Relative Attitude Sensor

Relative Attitude will be measured by an inertial measurement unit (IMU). The team is currently considering a Bosch BMI160 IMU.

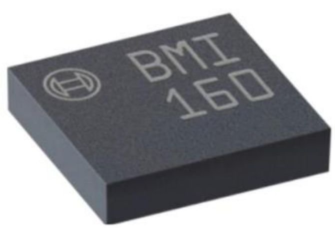


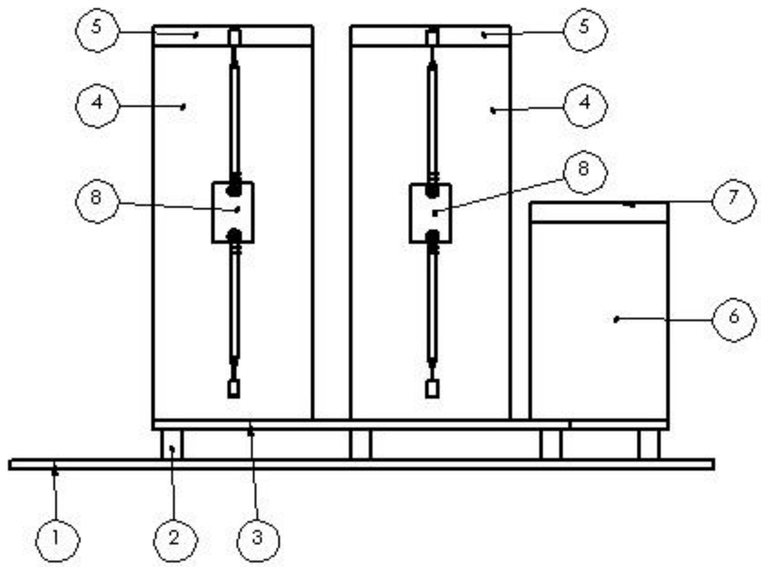
Figure 11: BMI160 IMU Chip

The BMI160 is a programmable unit that has a built in gyroscope and accelerometer. It communicates through I2C protocol. The inertial measurements are recorded with 16-bit resolution and can record shifts of position of 16.2 degrees per second and 16 g's of force. This allows for an accurate measurement of the position of the angular sensitive devices within the payload.

2.3 Mechanical Design

The entirety of the HASP payload will consist of four separate smaller payloads and a central HUB. Each of the four payloads will be virtually identical containing a Bismuth Germanate (BGO) scintillator, a photomultiplier tube (PMT), a battery pack power supply, a dipole antenna, and the control circuits. The central HUB will contain a DC to DC converter and telemetry components.

Each payload will be constructed from polystyrene foam and PVC panels. All sides of the main



ITEM NO.	PART	QTY.
1	HASP Mounting Plate	1
2	Mounting Pillar	7
3	Mounting Platform	1
4	Payload Box	4
5	Payload Box Lid	4
6	Central Hub	1
7	Central Hub Lid	1

Figure 12: Side view drawing of the HASP payload with a bill of materials

body of the payload box will be constructed from polystyrene foam except for the PVC bottom, which attaches to the PVC mounting platform. The raised PVC mounting platform attaches to the HASP mounting platform. Polystyrene foam will be used because it is durable, a good insulator, and lightweight.

The PMT and the scintillator have to be attached end to end. They are expected to be up to 25 centimeters long therefore will be placed vertically. The battery pack, consisting of 8 AA batteries in series, will be set at the bottom of the payload in a square-like configuration. The circuit boards required will be mounted on the interior walls of the payload boxes.

To protect components against extreme temperatures, aluminum mylar will be used on both the interior and exterior of the payload boxes. This material will contain heat produced by the electrical components on the inside and reflect infrared radiation from the sun. Further testing will be required to determine how much mylar is necessary. Another risk to electrical components is electrical arching because of the high voltage required for the PMT. To prevent this, a potting compound will be used on the high voltage source.

2.4 Software Design

Flight Software:

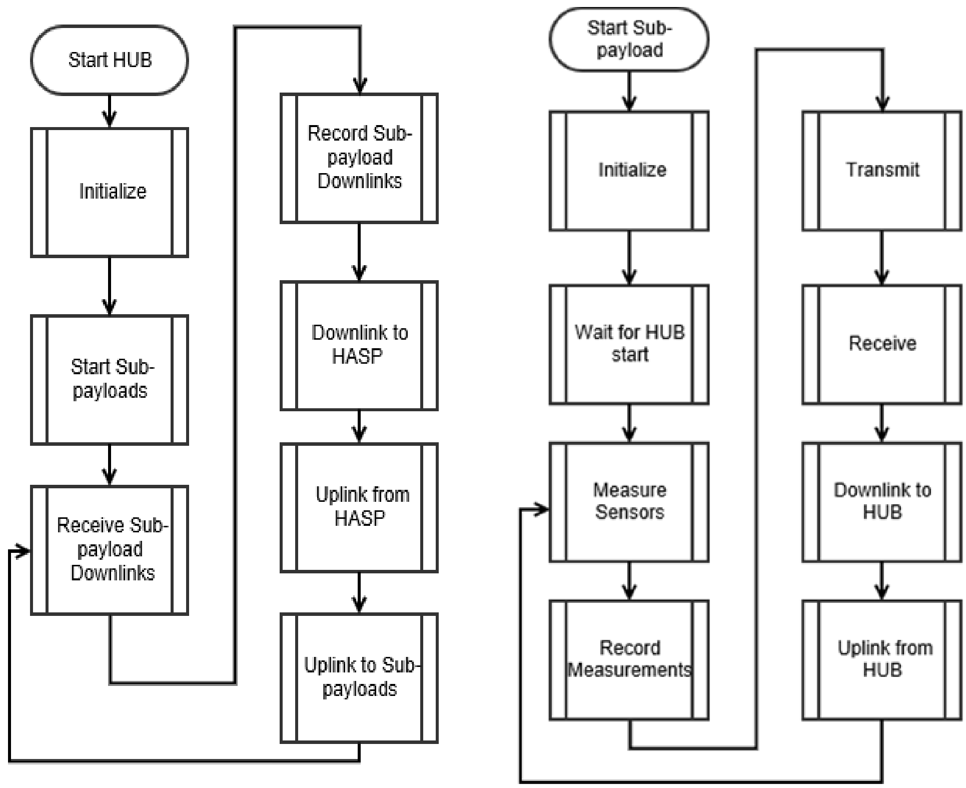


Figure 13: High Level Flight Software Flowchart for HUB and Sub-Payload

Flight control software will be divided into two programs, the main program, which will be used by the HUB, and the secondary program, which will be used by the sub-payloads. At initialization, both programs will initialize all variables and connections needed for payload function. The sub-payloads will then wait for a signal from the HUB to begin measurements. Once the HUB has begun measurements, it will receive downlink information from the sub-payloads, combine those transmissions for onboard records and downlink to HASP, then monitor and execute uplink commands sent through HASP.

Once given the signal to begin, sub-payloads will record the current GPS position of the sub-payload, measure the temperatures provided by onboard temperature sensors, and retrieve the payloads current attitude, and record the information to the onboard storage device. Once a measurement cycle is complete, the sub-payload will then transmit the information in a packet to the other sub-payloads. In order to avoid all sub-payloads transmitting at once, each sub-payload will have a different timing offset so that each payload transmits and receives at times appropriate to avoid transmission overlap. The sub-payloads will then, each in turn, downlink their measured information to the HUB. After downlink, the sub-payload will check for and execute uplinks from the HUB. Should there be a power failure or other system error, both the HUB and sub-payloads will use onboard storage to resume operations. Sub-payloads will send and receive transmissions to/from the other sub-payloads for the duration of the flight.

3.0 Team Definition

3.1 Team Positions and Roles

Table 1.1: Student Team Demographics						
	Name	**Role**	**Major**	**College Classification**	**G.D.**	**Ethnicity**
1	David Bordelon	Software	CSC	Senior	Spring 2016	Caucasian
2	Jordan Causey	Data Acquisition, Mechanical Lead	ME	Sophomore	Spring 2018	Black
3	Joshua Collins	Electrical Lead	EE	Senior	Spring 2017	Caucasian
4	Robert Cottingham	Communications	PHYS	Senior	Spring 2017	Caucasian
5	Allen Davis	Project Management	ME	Junior	Spring 2017	Caucasian
6	Victor Fernandez-Kim	COTEL Project Manager	ME	Senior	Spring 2017	Hispanic
7	Stephen Harb	Software Lead	CSC	Senior	Spring 2017	Caucasian
8	Brad Landry	Primary Contact, Project Management	ME	Junior	Spring 2018	Caucasian
9	Adam Majoria	Science Investigation Lead	PHYS	Senior	Spring 2018	Caucasian
10	Deanna Petty	Electronics Design	ECE	Senior	Spring 2017	Black
11	Chris Schayer	Software	SE	Senior	Fall 2017	Caucasian
12	David Williams	Science Investigation	PHYS	Sophomore	Spring 2018	Caucasian

Table 1: Team Positions and Roles

The Section Leads: Mechanical, Electrical, and Software, report to Project Management. The members of each section report to the section leads. Any other sections report directly to project management.

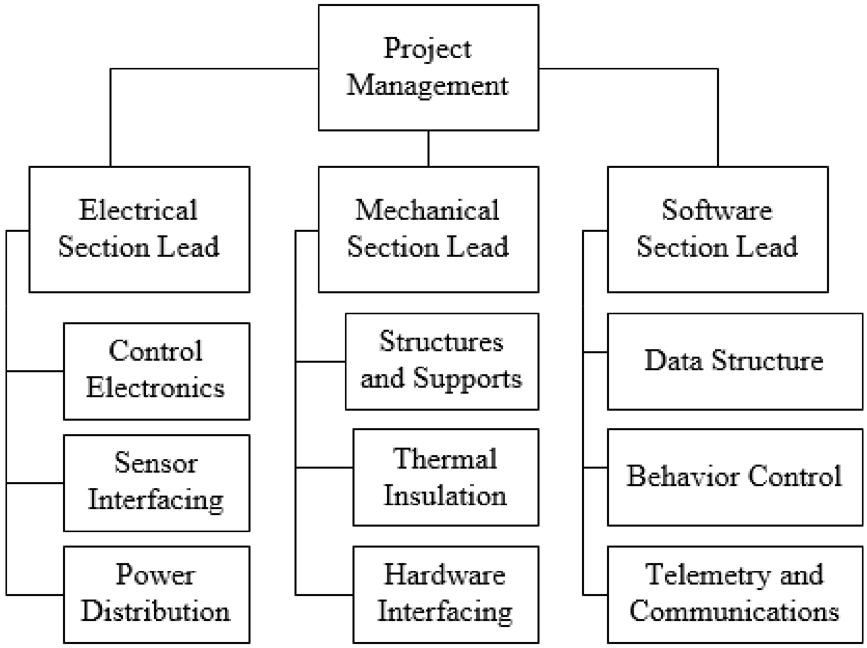


Figure 14: Team Layout

3.2 Team Contact Information

Student Team Contact Information		
Name	**Email address**	**Phone Number**
Victor Fernandez-Kim	vfernandezkim@gmail.com	(225) 400-8644
Joshua Collins	josbluehill@gmail.com	(985) 287-1093
Stephen Harb	stephenaliharb@gmail.com	(337) 207-2149
Allen Davis	adav156@lsu.edu	(251) 459-4578
Jordan Causey	jcaus17@lsu.edu	(225) 290-3613
Brad Landry	bland77@lsu.edu	(985) 805-0384
David Bordelon	dbord17@lsu.edu	(504) 579-6252
Chris Schayer	cschay1@gmail.com	(985) 237-0327
David Williams	davidwilliams4036@yahoo.com	(254) 458-5497
Adam Majoria	majoriaadam@gmail.com	(225) 614-0196
Diane Petty	pettydc@chart.net	(334) 467-1193
Robert Cottingham	rcotti1@lsu.edu	(225) 588-6329

Table 2: Student Team Contact Information

Table 1.2: Faculty Advisors				
Name	**Role**	**Contact Information**		**Address**
T. Gregory Guzik	Faculty Advisor	guzik@phunds.phys.lsu.edu	225-578-8597	359C Nicholson Hall, LSU
Michael Cherry	Faculty Advisor	cherry@phys.lsu.edu	225-578-6858	337 Nicholson Hall, LSU
Michael Stewart	Faculty Advisor	stewart@phunds.phys.lsu.edu	225-578-2250	327 Nicholson Hall, LSU
Douglas Granger	Faculty Advisor	granger@phunds.phys.lsu.edu	225-578-4427	326B Nicholson Hall, LSU
Brad Ellison	Faculty Advisor	stewart@phunds.phys.lsu.edu	225-578-8877	133 Nicholson Hall, LSU
Colleen Fava	Faculty Advisor	fava@phunds.phys.lsu.edu	225-578-8680	364 Nicholson Hall, LSU

Table 3: Faculty Advisor Contact Information

3.3 Timelines and Milestones

Task Name	Start	Finish
Preliminary Design Review	Mon 1/11/16	Mon 2/1/16
PDR Due	Tue 2/2/16	Tue 2/2/16
Critical Design Review	Wed 2/3/16	Mon 3/21/16
CDR Due	Tue 3/22/16	Tue 3/22/16
Pre-PSIP	Wed 3/23/1	Thu 4/21/16
Pre-PSIP Due	Fri 4/22/16	Fri 4/22/16
PSIP	Sat 4/23/16	Thu 6/23/16
PSIP Due	Fri 6/24/16	Fri 6/24/16
FLOP	Sat 6/25/16	Wed 7/27/16
FLOP Due	Thu 7/28/16	Thu 7/28/16
Payload Integration Ready	Mon 8/1/16	Mon 8/1/16
Fix Integration Issues (if needed)	Tue 8/9/16	Tue 8/30/16
Flight Ready	Tue 8/30/16	Tue 8/30/16
Data Analysis	Mon 9/12/1	Thu 12/8/16
Science Report Due	Fri 12/9/16	Fri 12/9/16

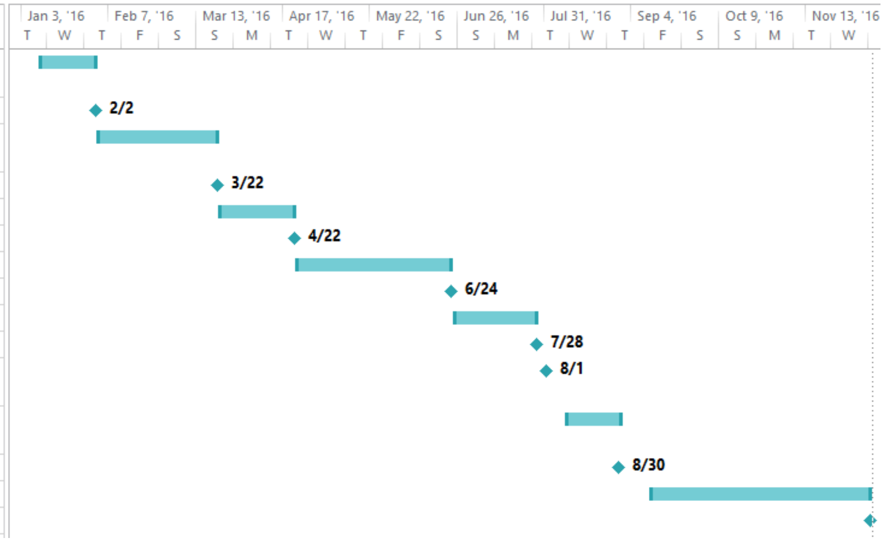


Figure 15: High Level Chart of Timelines and Milestones

Team Pleiades will structure milestones based along the requirements for the HASP flight, along with internal deadlines for a preliminary design review followed by a critical design review. The Pre-PSIP will be finished before LSU's finals and LSU's concentrated study period.

3.4 Flight Operations

COATL has no necessary orientation on the HASP platform and will use no analog channels or discrete commands.

COATL will have a full range of uplink commands to test the payloads full functionality and to control the power interfacing between the on-board power supply, HASP power supply, and the payload.

Pleiades will have the Project Manager and the three section leads present for the 2016 HASP Integration for COATL.

We will have at least one member present for Flight Operations to ensure the payload is integrated properly, though we hope to have more members available for Flight Operations. Other members involved in Flight Operations will be monitoring COATL's status from Nicholson Hall at LSU.

The commands for COATL are listed below:

Command and Control Communications			
Name	Bytes	Description	Check for Successful Command Execution
INFO downlink	00H, 00H	Full report on system operations detailing the HUB systems status, all sub-payload system status, and the environmental data for each. Sends a downlink of the INFO type for status.	Ground receives a downlink of INFO transmission type
HUB STAT downlink	01H, 00H	Full report on the system status of the HUB and associated environmental data. Sends a downlink of the STAT type for status of the HUB.	Ground receives a downlink of STAT transmission type
Sub-Payload Report, SPRX downlink	02H, XXH	Full report on the system status and associated environmental data of sub-payload with ID XX. Sends a downlink of the SPR type with the number of the associated payload ID.	Ground receives a downlink of SPRX transmission type
Payload Power Draw Report, PPDR	03H, 00H	Reports which sub-payloads and sub-payload systems are currently receiving HASP power. Sends a downlink of the PPDR type.	Ground receives a downlink of PPDR transmission type
Set Sub-Payload Radio to Receive Mode	04H, XXH	Sets the transceiver to receive mode for the sub-payload with the ID XX.	Turns on ADS indicator lights from all sub-payloads
Set Sub-Payload Radio to Transmit Mode	05H, XXH	Sets the transceiver to transmit mode for the sub-payload with ID XX.	Turns off receive indicator light from specified sub-payload
Set All Sub-Payload Radios to Receive Mode	06H, 00H	Sets all sub-payloads to only receive radio transmissions.	Turns on transmit indicator light from specified sub-payload

Send Data Transmission	07H, 00H	Tells the HUB to broadcast the most recent recorded data.	Downlinks most recent recorded data from the HUB

Table 4: Command and Control Communications

The downlinks sent through communication are listed below:

Name	Description	Format	Size
DataX	Header, shows the beginning of a data downlink, including which sub-payload it is from	DATAX	5 Bytes
Downlink Time	Time of data downlink	HH:MM:SS	3 Bytes
Lightning Flash Event Time	Time of Lightning Even in nanoseconds	HH:MM:SS:(Nanoseconds)	11 Bytes
TGF Event Time	Time of TGF event in nanoseconds	HH:MM:SS:(Nanoseconds)	11 Bytes
TGF Event Intensity	Intensity of TGF measurement	TGF XXXX	6 Bytes
Attitude	Measurement of system Attitude	ATD XXXX	6 Bytes
Checksum	Checksum for redundancy and confirmation	X	1 Byte
End	End tail for data Transmission	ENDD	4 Bytes
		Total	47 Bytes

Table 5: Data downlink format

Data: Format for required data from payload. The Lightning flash and TGF event will be on separate event timers for each payload. Each time a payload takes a data point it saves it locally, then moves the data into the HUB for organizing. Then each data link shall include which sub-payload the information is from.

Name	Description	Format	Size
HUB Status	Header, shows the beginning of an STAT downlink	STAT	4 Bytes
Downlink Time	Time of data downlink	HH:MM:SS	3 Bytes
HUB Status	Status of HUB systems, coded diagnostics to XXXX	HUB XXXX	6 Bytes
Internal Temperature	Temperature of inside of HUB	ITH XXXX	6 Bytes
Regulator Temperature	Temperature of HUB regulator	THR XXXX	6 Bytes

External Temperature	Temperature outside the HUB	ETH XXXX	6 Bytes
Most Recently Sent Command	Last command sent from the HUB to the sub-payloads	MRC XXXX	6 bytes
Checksum	Checksum for redundancy and confirmation	X	1 Byte
End	End tail for data Transmission	ENDD	4 Bytes
		Total	42 Bytes

Table 6: Status downlink format

STAT: The HUB status is a requested type that monitors the temperatures and status of the HUB. It is only sent on request from an uplink.

Name	Description	Format	Size
Info	Header, shows the beginning of an STAT downlink	INFO	4 Bytes
Downlink Time	Time of data downlink	HH:MM:SS	3 Bytes
Most Recently Received Command	Most recently uplinked command	HUB XXXX	6 Bytes
Time since Power on	Temperature of inside of HUB	ITH XXXX	6 Bytes
Current Draw	Current Draw from Power Supply	CRD XXXX	6 Bytes
Checksum	Checksum for redundancy and confirmation	X	1 Bytes
End	End tail for data Transmission	ENDD	4 Bytes
		Total	30 Bytes

Table 7: Info downlink format

Info: Info downlinks provide meta-information about the payload. Describing if the HUB uplink receiving is functioning right and if the current draw and powered on time are correct in the system.

Name	Description	Format	Size
Sub-payload Report	Reports the status of a specific sub-payload specified in an uplink	SPRX	4 Bytes

Downlink Time	Time of data downlink	HH:MM:SS	3 Bytes
Sub-payload Internal Temperature	Temperature of inside of sub-payload	SPI XXXX	6 Bytes
Sub-payload Regulator Temperature	Temperature of sub-payload regulator	SPR XXXX	6 Bytes
Sub-payload External Temperature	Temperature of outside of sub-payload	SPE XXXX	6 Bytes
Most Recently Received Command	Most Recently received command from the HUB	MRC XXXX	6 Bytes
Checksum	Checksum for redundancy and confirmation	X	1 Byte
End	End tail for data Transmission	ENDD	4 Bytes
		Total	36 Bytes

Table 8: Sub-payload downlink format

4.0 Payload Specifications

The payload is designed to fit within the large size HASP payload footprint. As currently designed, it is expected to weigh roughly 5438 g and use roughly 41 Watts of power.

4.1 Preliminary Drawings

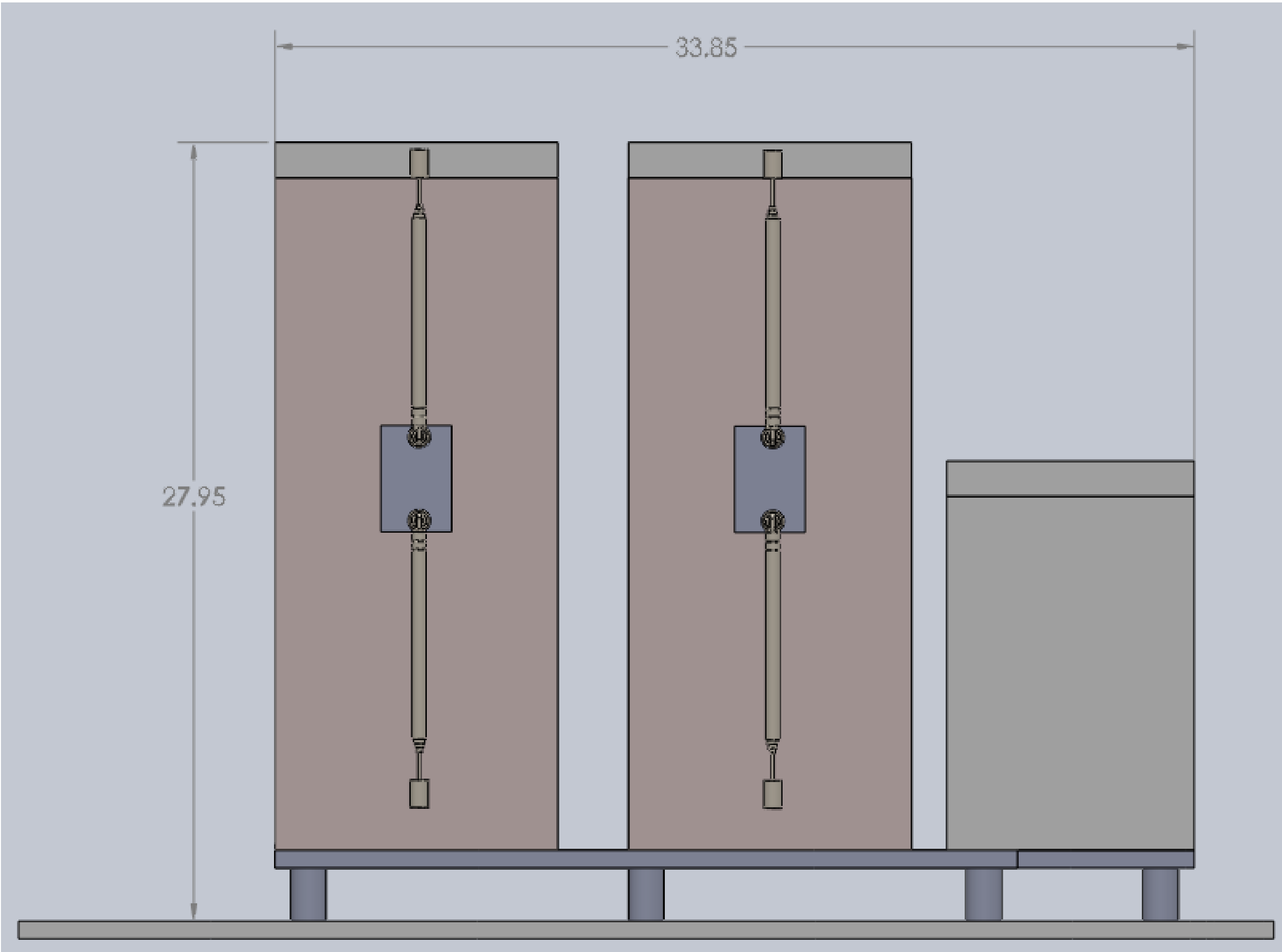


Figure 16: 3D rendering of the side view of COATL. COATL is 27.95 cm (11 in) tall, which fits within the maximum allowed height of 30 cm. COATL is 33.85 cm (13.33 in) long, which fits within the maximum allowed length of 40.32 cm (15.875 in).

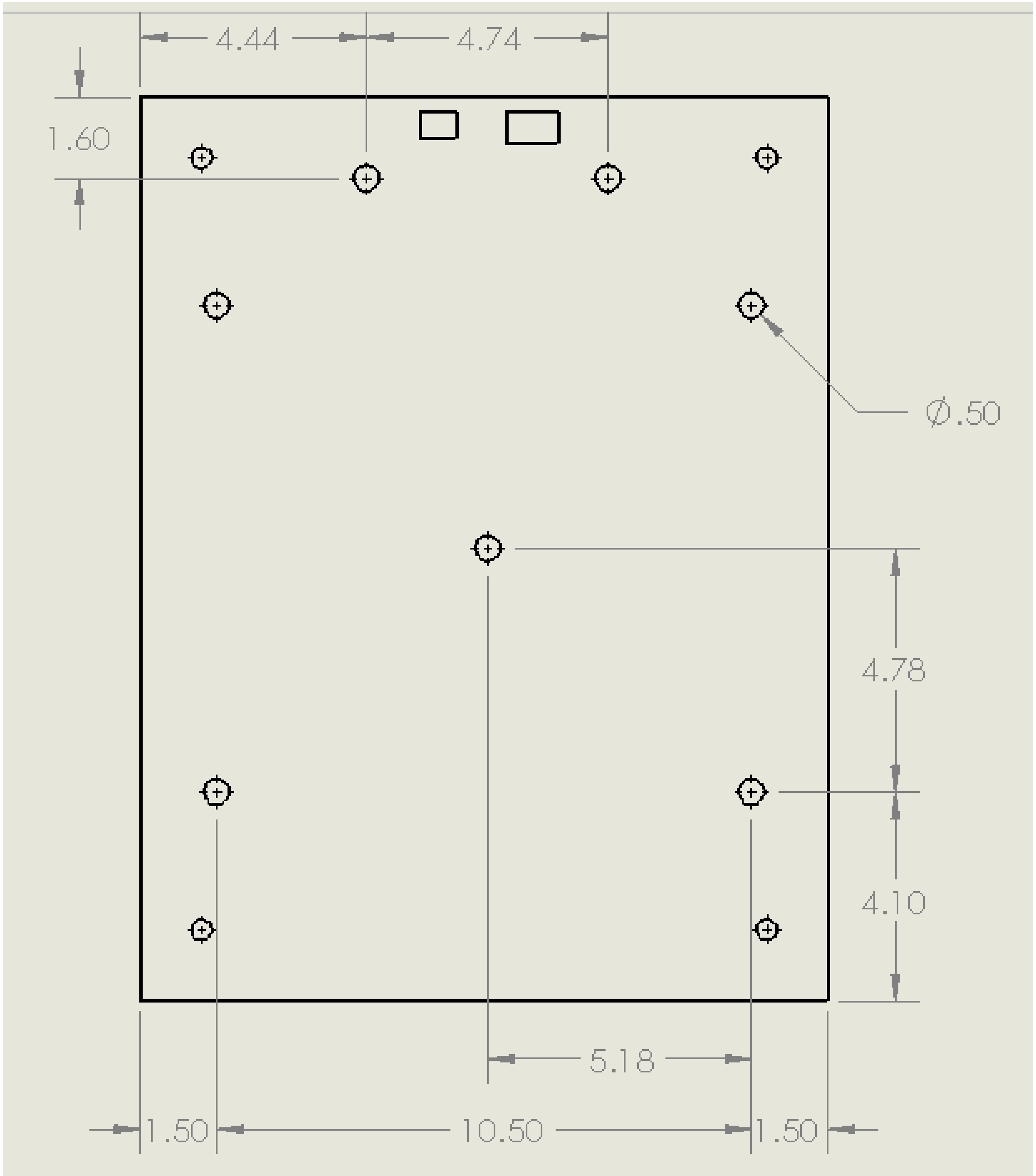


Figure 17: Anticipated HASP mounting plate modifications. Seven holes will be drilled in order to mount the payload. All of the drilled holes will be 0.5 inches in diameter. (units in inches)

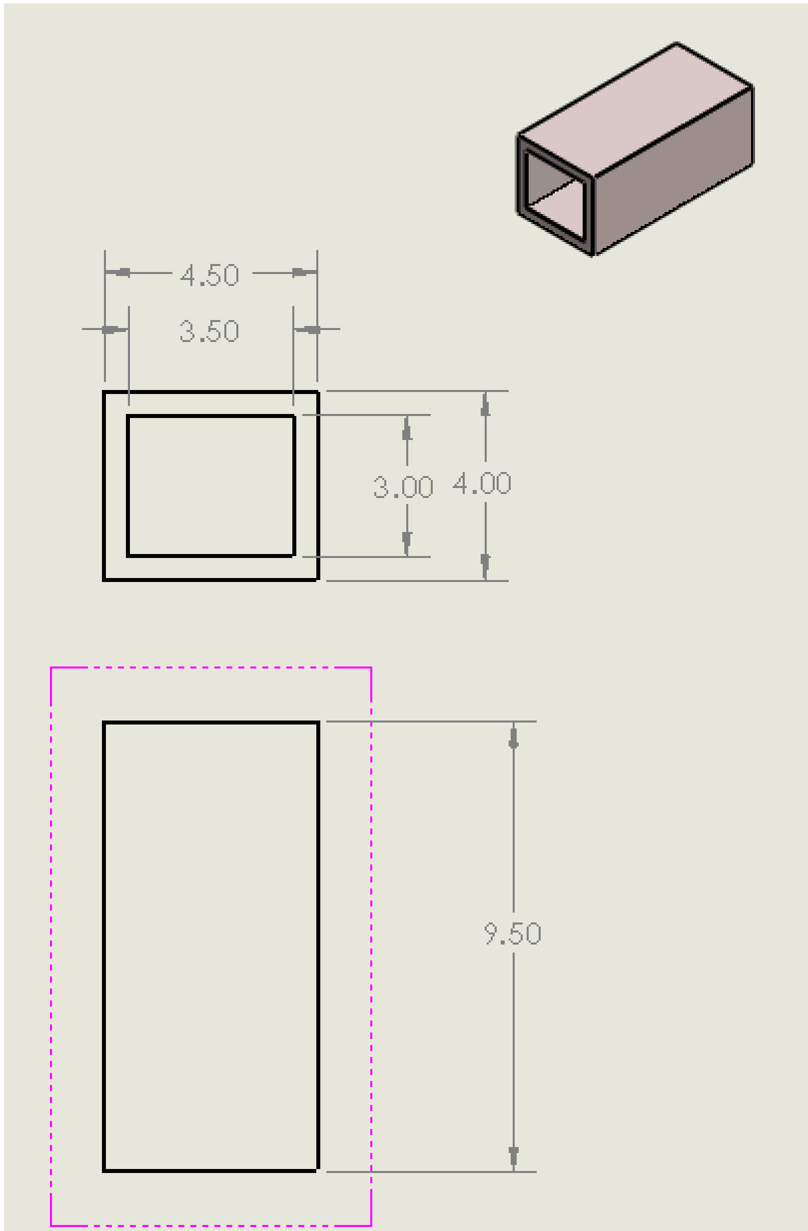


Figure 18: Payload Box detail with dimensions in inches. The Payload Boxes are primarily composed of 0.5'' thick Polystyrene foam.

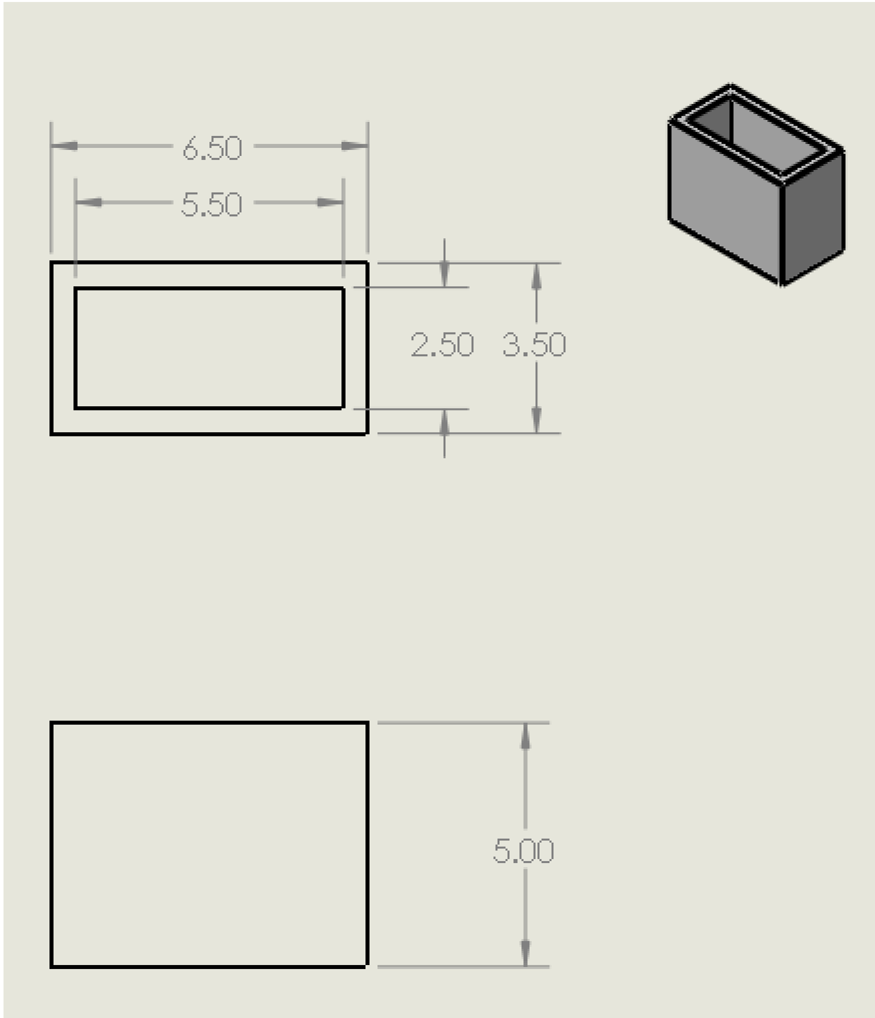


Figure 19: Central HUB detail with dimensions in inches. The Central HUB is primarily composed of 0.5'' thick Polystyrene foam.

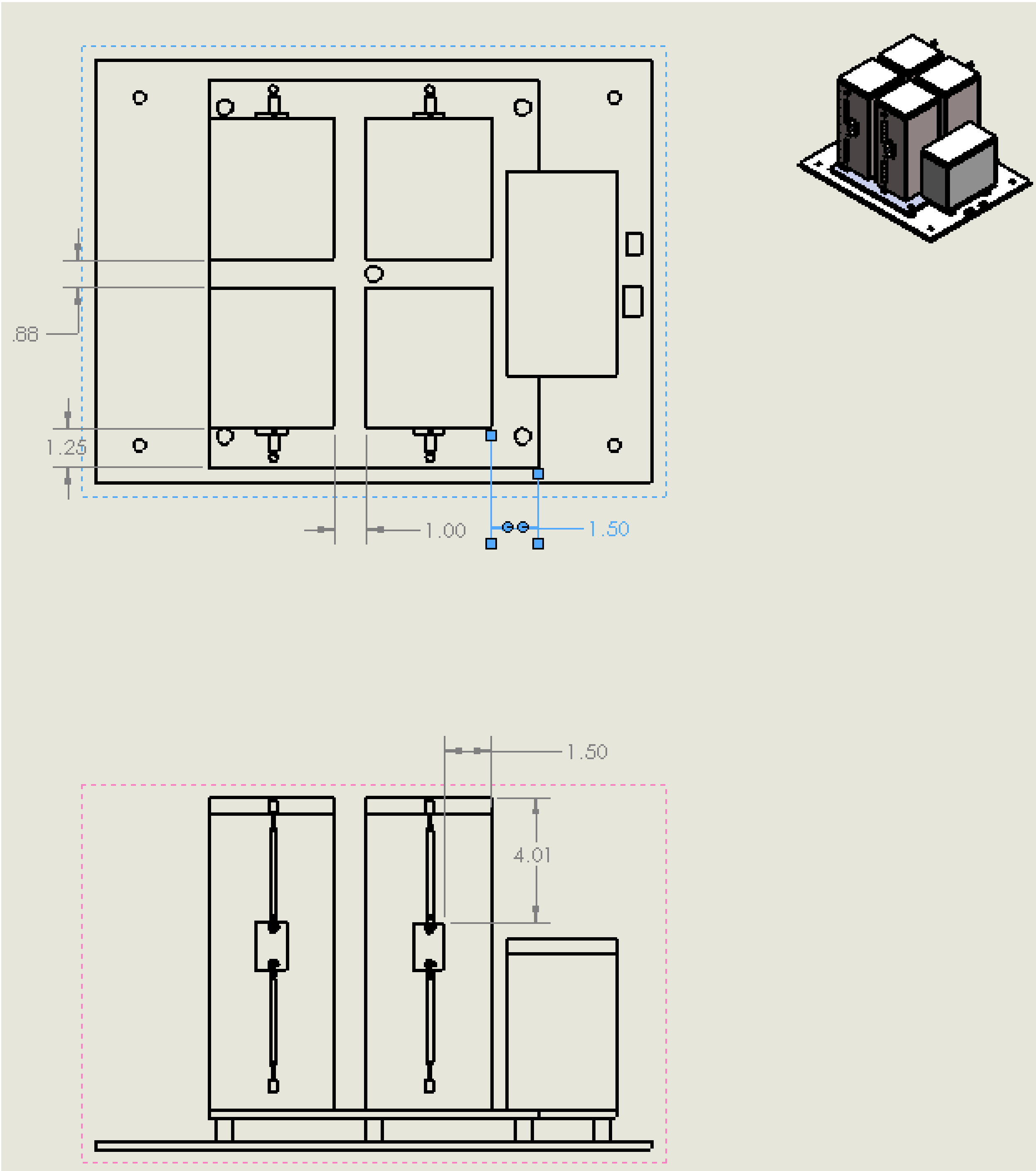


Figure 20: Full Payload Assembly drawing detailing antenna and payload box placement and the payload footprint on the HASP plate. Dimensions in inches.

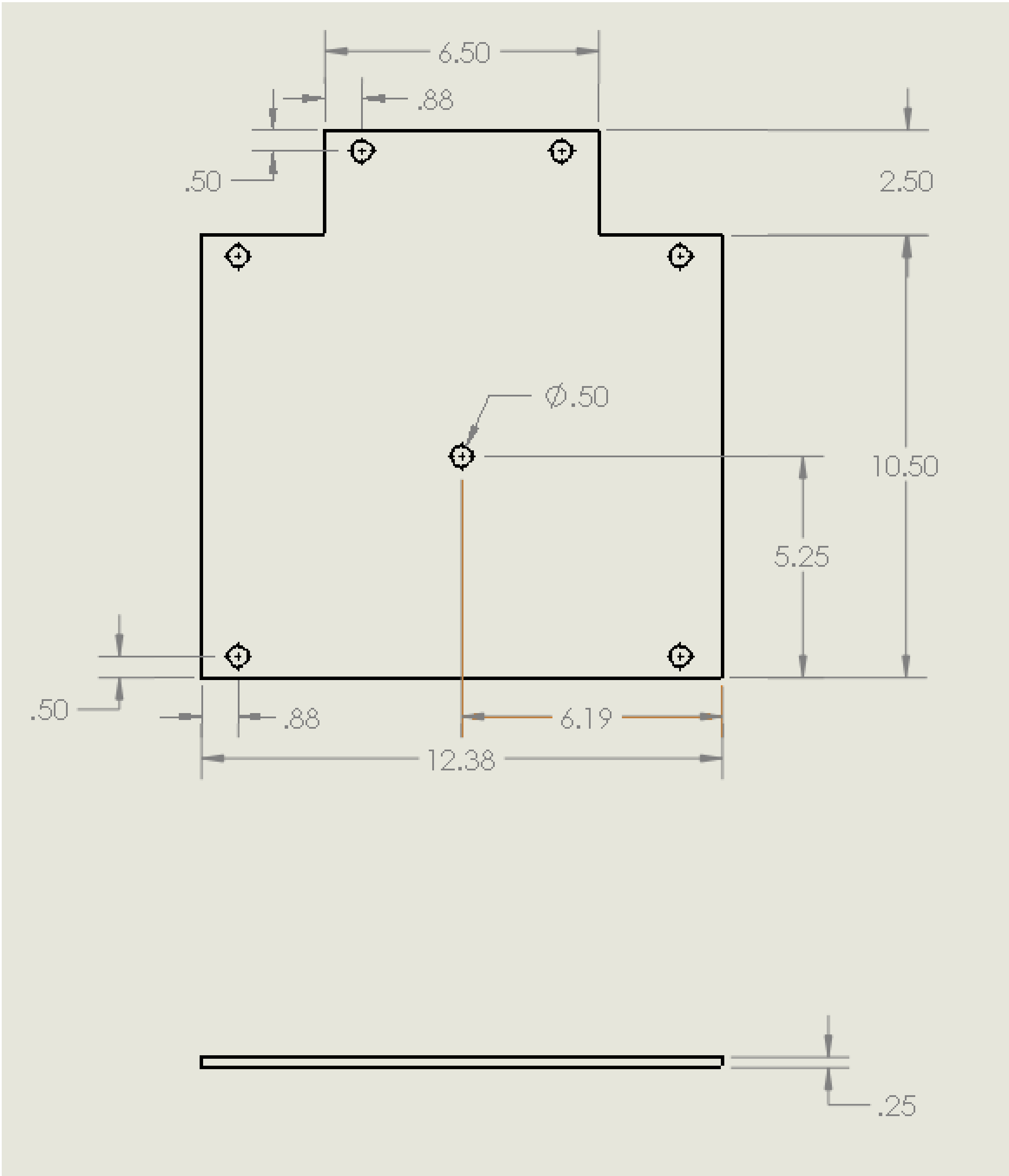


Figure 21: Mounting Plate detail with dimensions in inches. The mounting plate is composed of PVC.

4.2 Weight Budget

Component	Material	Mass (g)	Mass Uncertainty (±g)
4x Payload Boxes and 1x Central HUB	6.5 sqft. of 0.5’’ Polyethylene Foam, Econokote Thermal Barrier	100	20
Mounting and Support	2.1 sqft. of 0.25’’ PVC, Mounting Screws and Bolts	1000	500
4x Dipole Antenna	17 cm dipole antenna	90	20
DC Converter	APW P5 Series 5 Watt	88	10
Various Electrical Components	2x Voltage Regulator, AM Receiver, Transceiver, Wiring	15	5
Flight Computer	Raspberry Pi 2	45	10
Sensors	4x PMT, 4x Scintillator, 4x Attitude Sensor	4100	500
	Total:	5438	1065

Table 9: Weight budget

4.4 Power Budget

The COATL payload has 5 major components: the HUB and 4 sub-payloads. The total power draw of the entire payload is shown below. A detailed breakdown of the component draw is also shown.

Power Draw from HASP					
Component	Voltage (V)	Current Draw from Regulator (mA)	Efficiency	Current Draw from HASP (mA)	Power (mW)
30/12 Voltage Regulator	30	3033.67	87.00%	1386.82	41580
Totals				1386.82	41580

Table 10: Power Draw from HASP

Power Draw from Main Regulator			
Component	Voltage	Current Draw (mA)	Power (mW)
HUB	5	500.87	2504.35
Sub-Payload (x4)	5	2532.80	15020.00
Totals		3033.67	17524.35

Table 11: Power Draw from Main Regulator

HUB Power Budget Breakdown			
Component	Voltage	Current Draw (mA)	Power(mW)
Raspberry Pi 2	5	500	2500.00
Power Switch (x4)	5	0.8	4.00
Serial/RS232 Converter	5	0.07	0.35
Totals		500.87	2504.35

Table 12: HUB Power Budget Breakdown

Sub-Payload Power Budget Breakdown			
Component	Voltage	Current Draw (mA)	Power(mW)
Raspberry Pi 2	5	500	2500.00
GPS Board	5	20	100.00
Photomultiplier Tube	1200	0.1	120.00
Scintillator	1200	0.1	120.00
AM Receiver	5	5	25.00
Attitude Sensor	5	58	290.00
900MHz Transceiver	12	50	600.00
Totals		633.20	3755.00

Table 13: Sub-Payload Power Budget Breakdown

As shown from the above tables, COATL requires 41 Watt of power with a continuous draw of 1.3 A. This is less than the maximum allowed ratings for a large payload.

4.6 Risk Assessment

COATL has no pyrotechnics or radioactive materials on board. It will have a sealed container for the TGF detector, but that will be a low pressure seal of minimal risk. It will also contain a high voltage apparatus, but that will be sealed inside each sub-payload. If it causes issues with the electronics during testing, potting will be used. The payload also contains radio transmitters, so the band chosen to communicate between payloads will be set to avoid interference with the HASP communication bands.

5.0 Appendices

Science / Technology Traceability Matrix (Table B1)

Science Goal / Technology Goal	Science / Technology Goals	Measurement Requirements: Physical Parameters	Measurement Requirements: Observables	Instrument Requirements		Mission Requirements (Top Level)
Temporally and spatially measure TGFs and lightning strikes around thunderstorms	Detect, measure, record TGF event data	Radiation detector	TGFs	Gamma ray flash energy range	0.5 MeV - 20 MeV	Scientific Instrument Accommodation (See Table B2)
	Detect and record lightning event data	VLF antenna	Sferics	Detect Sferics		
	Timestamp each data point	Timing component Multiple detection instruments	Event Time Position of event	Timestamp accuracy	0 kV/m - 5 kV/m	
				Launch at least 3 payloads		
	Triangulate position of each data point	GPS positioning component	Position of detectors	Latitude	0.01 ms	
		Attitude Indication Component	Orientation of detectors	Attitude		

Mission Requirements	**Mission Design Requirements**	**Spacecraft Requirements**
Scientific Instrument Accommodation (From Table B1)	Flight Vehicle: High Altitude Balloon	Weight Limit: Under 20 kg
	Launch Date: Fall 2016	Interpayload Transmit Frequency: 900 MHz Range
	Mission Length: 15 hours – 20 hours	Transmission Power: 5 W
		Temperature Range: -60 C - 25 C
	Altitude: 0 km – 36 km	Shielding from light, water, and charge
Operate in Accordance with all Requirements Set forth by HASP	Max Size of Payload	38cm x 30cm x 30cm
		20 kg
	Power Draw	29VDC-33VDC
		Max 2.5 Amps
		EDAC 516 Interface
	Withstand G-forces	Vertical: 10G
		Horizontal: 5G
	Serial Communications	RS232 Protocol Over DB9 Connector
	Max Serial Downlink Speed	4800 bps
	Avoid Interfering with Other Payloads	

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