HASP Student Payload Application for 2015

Payload Title: High Altitude X-Ray Detector Testbed		
Payload Class: (check one) ☐ Small ☑ Large	**Institution:** University of Minnesota	**Submit Date:** December 19, 2014

Project Abstract

The work described in this proposal is motivated by the idea of using the X-rays and gamma rays emitted by celestial gamma ray bursts (GRBs) as observable signals for deep space relative navigation. The development of a compact GRB detector system is an enabler of this concept. The engineering objective of the experiment being proposed is to upgrade the compact X-ray detectors and their associated hardware that flew on the 2014 HASP mission. The primary upgrade for the 2015 payload will be the replacement of the previous detector system with one featuring improved energy resolution and precision timing capabilities, accomplished through the use of a different scintillator material and geometry as well as upgraded electronics. The scientific objectives of the experiment are to separate individual cosmic ray events into different energy bands, and to examine periods of higher photon flux in these bands along the flight trajectory for possible celestial body identification during flight. Another scientific goal is to quantitatively characterize the detector performance by determining the sensitivity range and energy resolution obtained during the HASP flight. The educational objective is to provide students with a hands-on experience in designing and testing avionics systems. The 2015 HAXDT payload will feature multiple discrete structures located on the HASP payload plate, including a 3U CubeSat infrastructure containing the primary experimentation. The payload is projected to have a mass of 5.6 kg, and current interface requirements include approximately 16 watts of power, and 540 bps of downlink bandwidth.

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1. Payload Description

The University of Minnesota's High Altitude X-Ray Detector Testbed (HAXDT) was developed to test and validate the performance of a compact X-ray detector and its associated flight hardware for the 2012, 2013 and 2014 HASP missions. Such compact high-energy photon detectors are being developed for use as navigation sensors for future deep space missions.

From year to year, HAXDT has built upon previous successes by achieving incremental milestones that push the development of the detector systems and supporting payload hardware closer to the long-term goal of the project. This began in 2012 with the first flight of HAXDT, during which a time history of high-energy photon events detected by the payload was collected. The 2012 HAXDT payload was incapable of measuring the energy levels of these incident photon events, however, so the engineering objective of the 2013 iteration was to add this capability. The added functionality on the 2013 HAXDT payload was attained through upgrades to the detector electronics and flight software, allowing both the time and energy of photon events to be recorded. Unfortunately, a launch mishap on the 2013 HASP flight prevented HAXDT from collecting flight data. Although the 2013 payload did not have the opportunity to perform a successful mission, the design goals of the payload were met, and in testing it demonstrated the ability to record the energy levels of photon events in addition to the data gathered by the 2012 iteration. The primary goals of the 2014 HAXDT payload were to add a second detector, and improve the precision of the energy measurement hardware. These design goals were also met and the 2014 payload completed its mission successfully, collecting time and energy information for photon events from both detectors.

The 2015 HASP cycle will initiate a paradigm shift for HAXDT. As in previous years, the primary goal of the 2015 mission is to continue to develop and improve the HAXDT detector systems, in particular by bettering the timing accuracy and energy resolution. This will be accomplished by replacing the plastic scintillators previously used in the HAXDT detectors with higher-performance thallium-doped cesium iodide (CsI(Tl)) crystals; significantly increasing the total detector volume and collection area; replacing the thick aluminium detector housings with thin beryllium sheeting to minimize photon attenuation; and re-evaluating the detector front-end electronics and energy measurement circuitry, replacing or redesigning components as needed. In addition to improving the detector systems, beginning in 2015 HAXDT will have the added goal of fully evaluating much of the hardware that will be required for a CubeSat demonstration mission. Such a mission has been proposed by a local company, ASTER Labs, Inc., under a NASA Small Business Innovation Research (SBIR) grant. The CubeSat design proposed by ASTER Labs includes a small array of compact high-energy photon detectors, and the goal of the mission is to demonstrate relative navigation capabilities between two CubeSats equipped with such detectors. The University of Minnesota (UMN) team has been working closely with ASTER Labs on the development of the HAXDT detector systems, and this partnership will continue in future project cycles as well.

As the 2015 HAXDT payload will evaluate additional systems beyond just the detectors, more hardware under test will be included than in previous designs. Further, properly evaluating the performance of some components and subsystems will require additional supporting hardware to be included. To provide ample size, weight, and power (SWaP) allocations for this additional hardware, the proposed 2015 HAXDT payload will occupy a large payload spot on HASP, rather than a small payload as in previous years. Some of the additional hardware that will be required for the 2015 HAXDT payload includes a high-precision timing source such as a chip-scale atomic clock (CSAC), and a high-end GNSS receiver. The CSAC will allow photon events measured by the detectors to be time-tagged more accurately. The high-end GNSS receiver, a NavCom SF-3050, will be used to provide a highly precise truth solution for the position of the payload throughout the HASP flight, on the order of centimeters of accuracy. This accuracy will be accomplished in one of two ways: either by receiving differential corrections broadcast from NavCom's proprietary StarFire service, or by using a second SF-3050 receiver fixed at the launch site and computing the carrier phase differential GPS solution in post-processing. With this truth solution for the payload position, HAXDT will not rely on its other GPS receiver (the NovAtel OEMStar) for a position solution at all times. Therefore the OEMStar, which is being considered for use on the CubeSat demonstration mission, can instead be evaluated as a unit under test. Tests that could be performed on the HASP flight include changing the channel configuration (which dictates how the 14 available tracking channels are split among GPS, GLONASS, and SBAS satellites) several times throughout the flight to see which one produces the most accurate position solutions.

The transition to a large payload is further justified by expanded student involvement, as it will allow for more secondary experiments and tests to be performed on the HASP flight. Beginning in 2015, the (extracurricular) UMN HASP team will accommodate projects associated with capstone courses in the Aerospace Engineering and Mechanics (AEM) and Physics departments. A group of AEM senior design students, many of whom have prior experience with the UMN HASP team, will work in the spring 2015 semester on building and testing CubeSat-like hardware which will ultimately be flown on the HASP flight as part of the HAXDT payload. In addition, senior physics undergraduates in the Methods of Experimental Physics (MXP) course offered in spring 2015 will assist in characterization of the HAXDT detector systems through laboratory tests. Other students from this course may also propose their own experiments to be flown on HASP, which would be easily accommodated given the additional SWaP afforded by a large payload. Further, members of the UMN High-Altitude Ballooning Team, led by Dr. James Flaten, are seeking to test a video downlinking system on the 2015 HASP flight. The majority of the hardware for this test will be proposed separately and not included in the HAXDT payload, with the exception of the camera, which will transmit video over a WiFi network to the 900 MHz downlinking system located elsewhere on the HASP platform.

The AEM senior design team has spent the fall semester investigating the design of a CubeSat that can perform a spectroscopy mission while orbiting a near-Earth asteroid. The team is interested in testing the performance of a 1U solar panel and a microcontroller in a space-like environment. The scientific goals of these tests are to analyze the performance of an off-the-shelf solar panel as well as the bit-writing characteristics of a microcontroller in near-space. The attitude of the solar panel will not be controlled, simulating a portion of a CubeSat whose outer shell is fully covered with solar panels. Radiation and temperature changes may cause bits to flip when a microcontroller is writing to non-volatile memory, and this sub-experiment will attempt to quantify these effects.

Although the UMN team is formally applying for a large payload spot on HASP, many of the engineering objectives could still be met with only a small payload spot. The detector systems could still be evaluated in this case, as may some of the CubeSat systems such as the solar panel.

However, the NavCom GNSS receiver could not be included, thus vastly limiting the testing that can be performed with the OEMStar and reducing the quality of the payload position truth solution. Also, while there may be sufficient space to include the camera for the video downlinking system, there may not be sufficient power or weight to accommodate it. Finally, any secondary experiments proposed by students in the MXP course would be extremely limited, or may not be included at all.

1.1 Background

The work described in this proposal is motivated by the idea of using celestial sources of high-energy photons (X-rays and gamma-rays) for deep space navigation. The impetus for this is that many envisioned future space missions will require spacecraft to have autonomous navigation capabilities. For missions close to Earth, Global Navigation Satellite Systems (GNSS) such as GPS are readily available for use. For missions far from Earth, however, other alternatives must be provided. While existing systems such as the Deep Space Network (DSN) can be used, latencies associated with servicing a fleet of vehicles may not be compatible with some autonomous operations requiring fast updates of the navigation solution.

Recent work has shown that variable celestial X-ray sources such as pulsars can be used as navigation beacons for determining the absolute position of space vehicles [1–9]. This approach is called X-ray navigation (XNAV). Current XNAV techniques are applicable to many deep space operations where GPS or other GNSS signals are unavailable or DSN tracking is not possible. While the current demonstrated accuracy of XNAV is not at the level of GNSS, XNAV is a nascent technology and it is reasonable to expect future increases in its accuracy. This increased performance will be the result of future improvements in sensors and navigation algorithms. The work described in this proposal is an effort in that direction. It deals with characterizing the performance of small and compact cosmic ray detectors. Such detectors placed on envisioned future deep space vehicles could be used to generate an accurate navigation solution at low power levels while taking up little space.

In addition to XNAV using pulsars, gamma-ray burst events (GRBs) may be used for navigation purposes. GRBs occur randomly in both time and space, often originating from outside of the galaxy. Caused by stellar explosions, GRBs consist of a wave of X-rays and gamma-rays with a very fast-rising intensity which then decays exponentially, causing an “afterglow” effect. This can last anywhere from a few seconds to several minutes. The majority of the photons from GRBs have energies in the range of 10 keV–1 MeV, although the exact energy characterization (as well as the time decay characteristics of the afterglow) are unique to each event. Therefore, while GRBs do not exist as beacons at known positions like pulsars, which foils traditional multilateration techniques, they may be used handily for relative navigation between cooperating spacecraft. This is done by correlating the characteristics of GRBs detected by each spacecraft to determine the time difference of arrival (TDOA) of each detected GRB. This is the principle behind ASTER Labs’ Gamma-ray source Localization Induced Navigation and Timing (GLINT) system, for which the CubeSat demonstration mission has been proposed. The GLINT navigation solution is particularly attractive since most spacecraft on deep space missions already include gamma-ray detectors as part of their instrument package. Further, unlike pulsar XNAV GLINT does not require pinpointing of specific photon sources, which eliminates the need for complex systems for precision pointing or to determine direction of arrival. The GLINT CubeSat demonstration mission will seek to attain a relative position accuracy of 1 kilometer or less, which will be more than sufficient for deep space missions.

1.2 Technical Challenge

While the detector systems developed for HAXDT are designed to be flexible enough to apply in the future to either pulsar XNAV or GLINT-based navigation systems, the primary focus of the HAXDT payload will be to evaluate the GLINT system. There are several reasons for this. First, pulsars that have been investigated for X-ray navigation fall in the 2–10 keV range [1-9], whereas at ballooning altitudes only X-rays above 20 keV are available for detection due to atmospheric absorption [10]. This means that no pulsars could be observed during the HASP flight, while it is possible (though unlikely) that a GRB may be observed. Second, the HAXDT detectors can more easily be tuned and tested for observing photon energies in the range of 50 keV–1 MeV. Detecting much lower energies while maintaining the same sensitivity and energy resolution would require specific highly-efficient detector geometry, photodiode placement, and photodiode-scintillator bonding techniques. Ultimately, these restrictions would limit the flexibility of the payload design and introduce unnecessary challenges.

Although detecting photons in the energy range of GRBs is easier than in the energy range of pulsars, there are still challenges associated with doing so. As mentioned earlier, GRBs originate from outside of our solar system and, from our perspective, occur at random times and intervals. The accurate detection of GRBs will rely on photon detectors with as large of surface area and volume possible. The technical challenge lies in designing a detector that will fit within the 3U CubeSat platform but be able to detect the randomly occurring GRBs in as omnidirectional a manner as is possible. To maximize the total detector volume and collection area, the 2015 HAXDT payload will consist of four individual detectors in close proximity, forming a small array equivalent to one much larger detector. In addition to high sensitivity, timing accuracy relative to a predefined standard is crucial, since ultimately GLINT requires comparing the GRB times of arrival between two spacecraft. This will be accomplished on HAXDT through the use of a CSAC, as noted previously. The CSAC will be slaved to the OEMStar GPS receiver's pulse-per-second (PPS) output to maintain synchronization with GPS time. The PPS output is functional even when the receiver does not have a position fix, and thus performing tests on the OEMStar such as changing the channel configuration will not have any lasting effects on timing accuracy.

1.3 Hypothesis

While it is unlikely that HAXDT will observe a GRB during the 2015 HASP flight, the background cosmic radiation observable at balloon altitudes will be sufficient to evaluate the performance of the detectors. With the newly-upgraded CsI(Tl) detectors, satisfactory performance would consist of the detection of photons in the full energy range of 50 keV–1 MeV, with an energy resolution better than 20% full width at half maximum (FWHM). Further, individual photon events should be timestamped with accuracy on the order of 0.1 microseconds or better.

Preliminary ground testing of the new CsI(Tl) scintillator crystals was performed by Mr. John Goldstein at the Johns Hopkins University Applied Physics Laboratory. Mr. Goldstein evaluated two different detector configurations using CsI(Tl) scintillator crystals. The first configuration consisted of a square rod scintillator, measuring 2 cm x 2 cm x 8 cm. The photodiode was placed on one of the ends of the rod. The second configuration used a "flat paddle" scintillator, measuring 4 cm x 4 cm x 2 cm. The photodiode was placed in the center of one of the larger faces of the scintillator. This second configuration will allow for greater flexibility in integrating the detector systems into the payload design, since the photodiodes can be conveniently placed below the scintillators, where they could immediately interface with the front-end electronics without requiring any cabling. In the first configuration, the photodiodes would be located in a narrow space between the scintillators and the interior wall of the CubeSat-like structure, making them more difficult to access and requiring cabling to interface with the electronics. The first configuration will likely produce better overall performance, though, since the scintillation photons can be more efficiently absorbed by the photodiodes. The results of the preliminary tests, performed using a cesium-137 radioactive source, are shown in Figure 1.

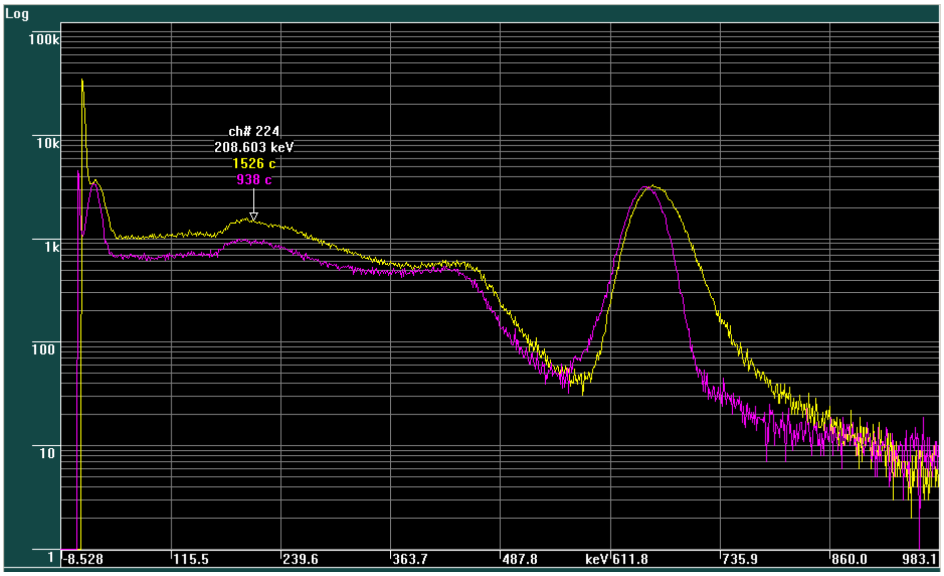

Figure 1. Photon energy spectra from lab testing of the new CsI(Tl) scintillator crystals, in the rod configuration (magenta) and the paddle configuration (yellow).

The paddle configuration is shown in yellow, while the rod configuration is shown in magenta. The test confirms that the rod configuration has better performance, with an energy resolution of 6.5% FWHM at 662 keV as opposed to only 8% FWHM from the paddle. Further, the lower noise floor with the rod improves sensitivity at low energies (< 50 keV).

1.4 Payload Systems and Principle of Operation

A high-level diagram of the payload's systems is shown in Figure 2 below. The interior components of the 3U CubeSat structure consist of: a four-channel detector board including preamplifiers for each channel and a high voltage power supply (HVPS) to provide the bias voltage for the detectors; four individual detector assemblies in a common housing; photon energy measurement hardware, either the previously-used pulse height analysis circuitry or a multichannel analyzer (MCA); a NovAtel OEMStar GPS receiver and associated antenna; a VectorNav VN-100 inertial measurement unit (IMU); power regulation, protection, and distribution circuitry; and a flight computer with an SD card for data logging. These components are shown in Figures 5–10. Power is provided by HASP and is regulated to +12 VDC to power all payload systems as seen in Figure 3. The power circuit also provides protection from reverse polarity and limits the current draw to just under 2.5A to prevent inrush current spikes. The schematic for this circuit is shown in Figure 4.

In addition to the 3U CubeSat structure, the payload includes two additional structures. One of these structures houses the NavCom SF-3050 GNSS receiver and separate data logging system, along with the antenna which is mounted on a mast. The other ancillary structure houses the camera for the video downlinking system, a WiFi-enabled GoPro HERO3+. The camera is mounted on a servo-controlled rotating platform inside of a clear acrylic structure. The lower portion of this structure houses an Arduino microcontroller and an XBee radio. The Arduino receives commands from the video downlinking system through the XBee, and controls the servo position accordingly. The video from the GoPro is broadcast over a short range via WiFi, which is then rebroadcast in the 900 MHz band over a long range by the video downlinking system.

Additional auxiliary structures will be included as needed to house further secondary experiments that cannot fit within the existing structures.

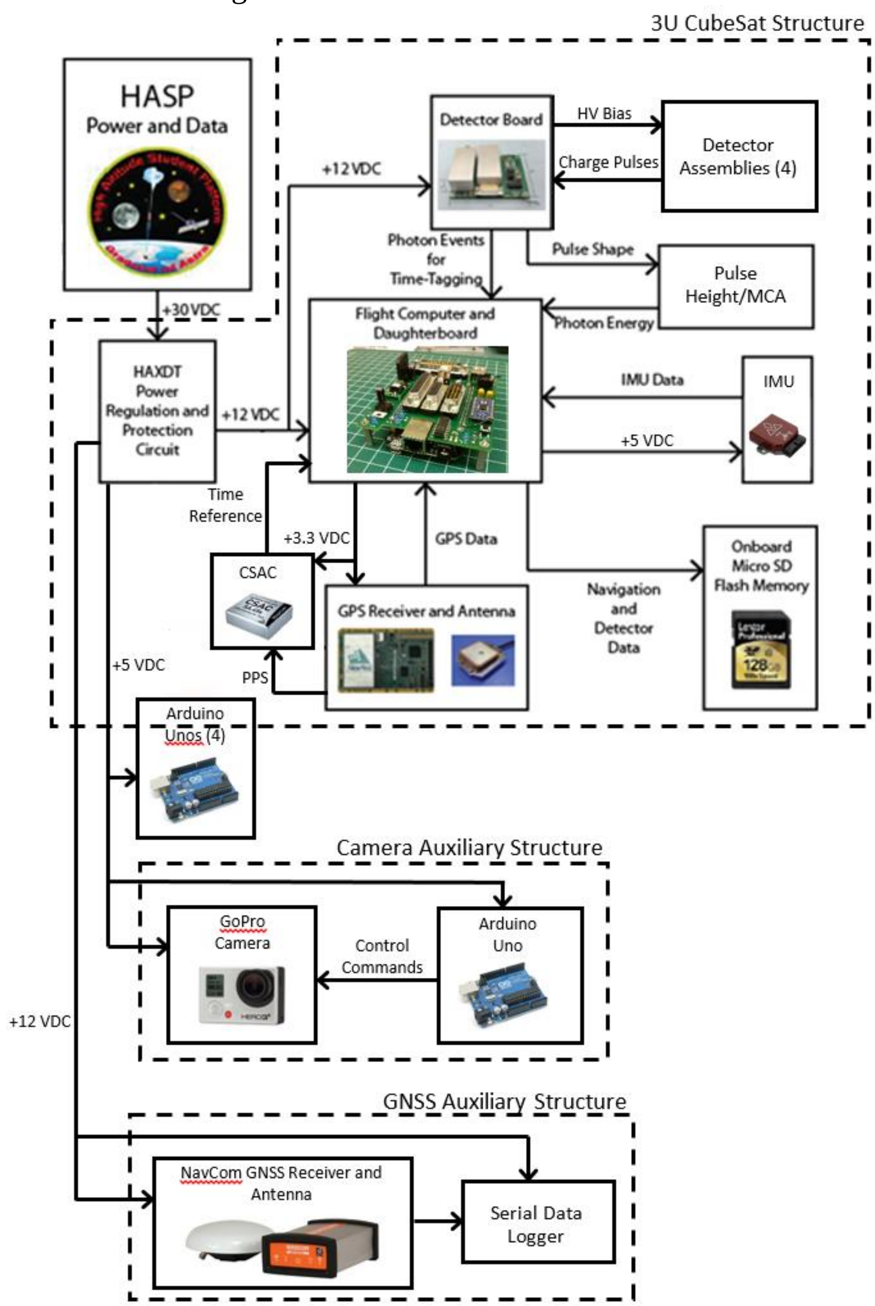

Figure 2. High-level system diagram for the full 2015 HAXDT payload, including the 3U CubeSat structure and the auxiliary structures for the video downlinking system camera and the NavCom GNSS receiver.

1.4.1 Sensor Payload

The detector assemblies are seated in an aluminum housing with a thin (1 mm or less) beryllium zenith face which is reinforced with ribs for structural integrity (Figure 5). Each assembly consists of an avalanche photodiode (APD) affixed to a CsI(Tl) scintillator crystal with optical grease. The geometry of the four scintillators has yet to be determined; either the paddle option will be selected for flexibility of design, the rod option will be selected for best performance, or two rods and two paddles will be used side by side to thoroughly compare the two configurations. The assemblies are then wrapped in polytetraflouroethylene (PTFE) tape (Figure 6). Light flashes generated by high-energy particle interactions with the scintillators are converted to electric charge by the APDs, and then shaped into voltage pulses by the detector board. The detector board also includes discriminators for each channel to allow for time-tagging by the flight computer. The voltage pulses are fed through the energy measurement circuitry as well, which forwards this information to the flight computer for logging.

1.4.2 Structure

The primary structure is composed of 6061-T6 aluminum in a 3U CubeSat configuration. The four side panels are 1/16" aluminum sheet. These panels are held together by four edge rails, which are joined by an aluminum plate at the bottom of the structure. The components are fastened together with size #4-40 self-locking 18-8 stainless steel socket head cap screws, and the bottom plate is affixed to the HASP Payload Mounting Plate with 1.25" long ATSM A307 ."-20 bolts. The exterior walls of the side panels will be coated with a white spray-on epoxy, while the inside walls will be polished to a mirror finish. The white exterior coating will inhibit energy absorption, thus protecting the payload from overheating at float altitudes. The reflective interior will assist in keeping the payload warm as it passes through the extreme cold environment encountered in the tropopause by. The auxiliary structures which house the NavCom GNSS receiver, the GoPro camera, and any other secondary experiments will be constructed using similar methods. These structures, of course, do not need to conform to CubeSat standards.

1.4.3 Computer and Data Logger

The flight computer on the 2015 HAXDT payload has yet to be selected. Most likely, it will be based on a 32-bit ARM processor to resemble the technology currently used in high-end 3U CubeSats. The BeagleBone Black, used in the 2014 HAXDT payload, may be a suitable option for the 2015 payload as well. However, the final design may include changes in the required form factor or the software development procedures which could lead to a different selection. The flight code, written in C, will be based off of code written for the previous HAXDT missions. In addition to collecting data from the detector systems, the flight computer will gather and log GPS data from the OEMStar, IMU data from the VN-100, and potentially further data from secondary experiments (such as solar panel output). The data generated and collected during the flight is logged on-board in non-volatile storage throughout the flight for post processing.

The NavCom GNSS receiver will be paired with its own dedicated data logging system. This will either consist of a simple serial data logger, or a microcontroller or microprocessor with data logging capabilities (for example a Raspberry Pi, BeagleBone Black, or Arduino).

To evaluate environmental effects on low-cost microcontrollers and flash storage, four Arduino Uno boards will be continually writing a known pattern of bits to their respective SD cards. Each Arduino will be exposed to a different environment. One Arduino will be completely exposed to the outside environment and serve as the control; another will be placed inside one of the aluminum structures, providing some thermal and radiation protection; another will be shielded by lead to provide radiation shielding but minimal thermal protection; and the final Arduino will be covered with multi-layered insulation (MLI) to provide thermal protection but minimal radiation shielding. In post-processing, the data on the SD cards will be compared and the effectiveness of the different shielding and thermal protection schemes will be characterized. The thermal effects can be compared quantitatively by also including a temperature sensor near each Arduino; the radiation effects will likely only be compared qualitatively, however.

1.4.4 System Operation

Once HASP operations begin, power will be provided to HAXDT and the payload will remain on for the duration of the flight. There are no control capabilities included on the payload, thus, there are no commands to be sent to the payload during flight. The exception to this may be camera control commands for the video downlinking system, but these would be sent through radios directly associated with this system and not rely on the HASP systems for uplink. Therefore, a single power up command from the HASP systems will be sufficient for payload operation. All data will be stored on-board the payload for post processing. The downlink will be utilized to monitor payload health by sending a data packet every second as outlined in Section 3 below. If data collection is not proceeding as expected, then a request to power cycle the payload will be made.

2. Team Structure and Management

HAXDT will be constructed by a student team led by Seth Frick as a part of his master's research. Mr. Frick will be responsible for team management, monthly report submission and teleconferences, and hardware and material procurement. Mr. Frick will also serve as the Principal Engineer for the project, with extensive engineering responsibilities in the energy measurement portion of the X-ray detector system and the operation of the attitude and navigation sensors. Several undergraduate students who worked on the 2014 payload will continue their contributions for the 2015 project cycle. Josiah Delange will lead the development of the new detector system and integration with the payload, and will also begin to assume management responsibilities towards the end of the project cycle after Mr. Frick graduates. Alec Forsman will assist the flight computer and software development. Haley Rorvick will lead the design and fabrication of the payload structure. The AEM senior design team members will assist in payload fabrication and the integration of the new electrical hardware and sensors. The physics students in the MXP course will assist in the design and testing of the detector systems. A few first-year graduate students in the AEM department without prior HASP experience have expressed interest in contributing for the 2015 project cycle as well. Additional undergraduate participants may be recruited through the Minnesota Space Grant Consortium High-Altitude (Sounding) Ballooning Team to assist the team leads in payload operation and development. One such student is the Ballooning Team Lead, Christopher Gosch, who will serve as the technical point of contact for the video downlinking system.

Dr. James Flaten is supervisor for the University of Minnesota ballooning team and provides expert advice in balloon flight operations. Dr. Suneel Sheikh is the CEO of ASTER Labs, Inc. and an expert in X-ray navigation. Dr. Sheikh provides ongoing consultation in the development of this payload system. Mr. John Goldstein is an engineer at the Johns Hopkins University Applied

Physics Laboratory and an expert on the development of photon and energetic particle detector systems for spacecraft. Dr. Kevin Hurley is a researcher in high-energy astrophysics at the University of California at Berkeley. Dr. Hurley provides information on GRB events which may have been observable during HASP flights. Dr. David Chenette's laboratory provided the nuclear pulse detection circuit vital to the design of the X-ray detector system and provides ongoing technical advice and expertise. Dr. Keith Gendreau developed an X-ray detector package similar to the system on HAXDT, and also provides technical expertise in the integration of the X-ray detectors into the system. Dr. Adhika Lie is a GNSS engineer at NavCom Technology, Inc. and a former UMN graduate student. Corporate sponsors include Amptek, Inc. and Saint-Gobain Crystal, who each provided donated parts that were crucial to the development of the detector systems; and NavCom, who have provided the UMN AEM department with several SF-3050 receivers for research purposes. Funding is provided by the Minnesota Space Grant Consortium.

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Table 1. Mailing addresses, affiliations and contact information of key personnel.

It is anticipated that between three and six students will participate in integration at CSBF and possibly two students will participate in flight operations at Ft. Sumner. Table 2 below shows the anticipated timeline and milestones for this project (milestones in bold).

Month of 2015	Description of Work
January	Undergraduate recruitment and training. Design new detectors and prototype. Acquire flight hardware.
February – March	Develop structure and finalize detector design. Build detectors and perform laboratory tests. Preliminary flight system design.
March – April	Final flight system design and integration with new detectors. Fabrication of payload structure. Development of flight software.
April 24	**Preliminary PSIP document deadline.**
April – May	Full systems integration and testing.
June	Final assembly and testing including thermal vac test.
June 26	**Final PSIP document deadline.**
July	Finalize flight operations plan. Verify all systems go.
July 30	**Final FLOP document deadline.**
August 3-7	Student payload integration.
August	Correct unforeseen issues, if any.
September	Launch. Parse and extract flight data upon payload’s return to UMN.
October	Analyze results and begin science report.
November	**Complete data analysis and final report.**
December	**Submit final report and prepare 2016 application.**

Table 2. Preliminary 2015 HASP timeline for the UMN team.

3. Payload Specifications

As previously mentioned, the 2015 HAXDT payload will be designed for the **large payload** classification. The primary structure, however, is designed to conform to CubeSat standards, based on one or more cubes with internal dimensions of 10 cm x 10 cm x 10 cm. A single cube is known as a 1U, or unit volume, configuration. The 2015 HAXDT payload primary structure will be in a 3U configuration. This implies that the payload height will be 30 cm, thus assuring that the payload falls within the HASP height guidelines for the given payload specification. The footprint of the HASP mounting plate will be further occupied by additional auxiliary structures housing support hardware and secondary experiments. If necessary, the 2015 HAXDT payload can be modified to comply with the small payload specification, but doing so would require the majority of the supporting hardware and secondary experiments to be eliminated. This would have a negative impact on the overall long-term development of HAXDT, and severely limit student involvement on the UMN HASP team.

There are presently no serial uplink or additional discrete commands anticipated for the payload. However, some downlink bandwidth will be required for system health monitoring. The serial link will be connected at 4800 baud using 8 data bits, no parity, and 1 stop bit as described in the HASP Student Payload Interface Manual. The serial downlink traffic from HAXDT will be 540 bps (the 60 byte packet outlined in Table 3 below plus serial framing bits) sent over the 4800 baud connection. This implies we will initiate data transfer at a frequency of 1 Hz. The data rate and/or packet structure may change during the development of the payload to include metrics which will be used to determine proper operation of all payload components in real time. Any such changes will be detailed in future documentation. If the data received via the downlink indicates that data collection is not proceeding as planned, then a power on/power off command will be requested. Thus, the only discrete line required is the default line that powers the payload on and off.

Byte	Title	Description
1-2	Header	Indicates beginning of message.
3-10	GPS second	Seconds from beginning of GPS week.
11-18	X_Pos	ECEF x-coordinate, from OEMStar.
19-26	Y_Pos	ECEF y-coordinate, from OEMStar.
27-34	Z_Pos	ECEF z-coordinate, from OEMStar.
35-42	Ampient_Temp	Ambient internal temperature of the 3U CubeSat payload.
43-46	Detector 1 photons	Cumulative number of photon events recorded by Detector 1.
47-50	Detector 2 photons	Cumulative number of photon events recorded by Detector 2.
51-54	Detector 3 photons	Cumulative number of photon events recorded by Detector 3.
55-58	Detector 4 photons	Cumulative number of photon events recorded by Detector 4.
59-60	Footer	Indicates end of complete data record.

Table 3. Preliminary HAXDT downlink packet structure.

No analog downlink channels are expected to be utilized for the 2015 HAXDT payload.

Anticipated procedures at the Student Payload Integration include testing that the HAXDT interface with the HASP gondola is configured properly via the EDAC 516 connector; that power is being delivered and does not exceed the allowed current draw; and that the payload collects, downlinks, and stores data without issue. If the payload passes these tests, then it will be subjected to the planned thermal/vacuum testing. Assuming success at integration, procedures at flight operations are anticipated to consist solely of making sure the payload is connected properly and powers up without issue. It should be noted that HAXDT will undergo thorough integration testing as well as thermal/vacuum testing at the University of Minnesota before integration.

3.1 Payload Mass and Power Budget

The payload will use the EDAC 516 connector to provide power to all systems as indicated in Figure 3. Voltage will be regulated and distributed according to each system's power requirements as shown in Figures 3 and 4. Table 4 below outlines the power and mass budgets for the payload components. Regardless of the design changes which may yet be made (modifying the payload auxiliary structures, adding further secondary experiments, etc.), the mass and power specifications of the payload will remain well within the limits of 20 kg and 75 W, respectively, for the large payload classification.

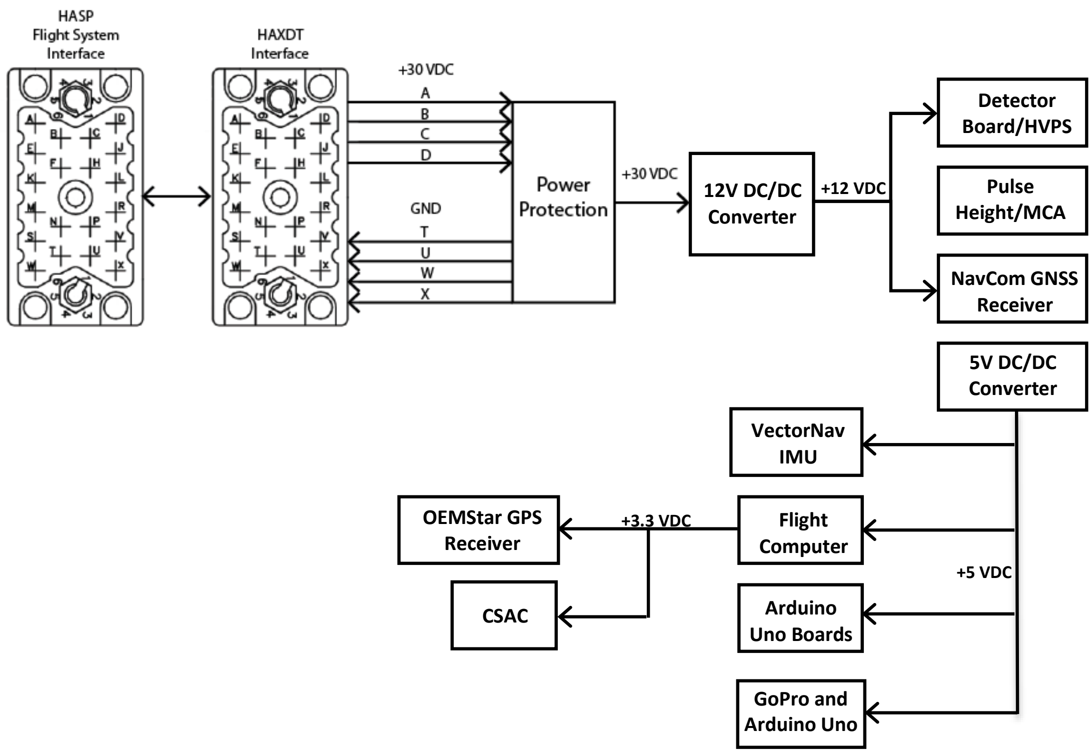

Figure 3. Systems-level diagram showing the power distribution from the HASP flight batteries into all HAXDT payload components.

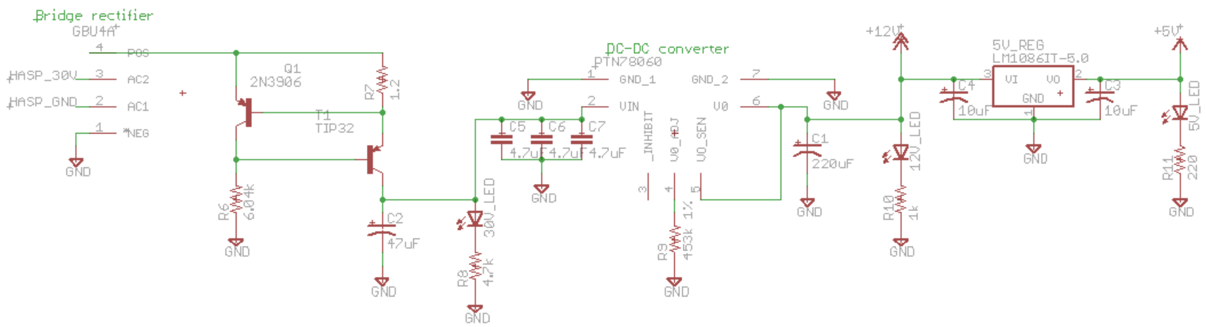

Figure 4. Power protection and regulation circuitry used on the 2014 HAXDT payload. The 2015 payload will use a similar circuit, redesigned slightly to accommodate the increased power consumption.

Component	**Mass [g]**	**Mass Uncertainty [g]**	**Power [W]**	**Power Uncertainty [W]**
Flight computer, daughterboard, power circuitry	200	50	2.5	0.5
Detector systems, including energy measurement	800	100	2.0	0.5
VectorNav IMU	20	5	0.2	0.05
Microsemi Quantum CSAC	35	2	0.12	0.05
OEMStar GPS receiver and antenna	40	5	0.36	0.05
NavCom GNSS receiver and antenna	1000	50	6.0	0.5
NavCom receiver data logger	40	10	0.5	0.1
Structure and mounting hardware	3000	500	-	-
Arduino microcontrollers and SD card shields (4)	175	25	2.0	0.5
Solar Panel	50	5	-	-
GoPro HERO3+ camera	75	5	2.0	0.5
GoPro camera mount	150	50	-	-
Arduino and XBee	40	5	0.5	0.1
Total	**5625**	**812**	**16.18**	**2.85**

Table 4. Preliminary mass and power budget for the 2015 HAXDT payload.

3.2 Payload Location and Orientation

The experimental goals are independent of the physical location on the HASP gondola. However, the large GNSS antenna for the NavCom receiver could potentially obstruct the view of CosmoCam if the HAXDT is placed too close to the camera.

4. Figures and Preliminary Drawings

The figures below include the following: a model of the GLINT detector system proposed for the CubeSat demonstration mission, upon which the 2015 HAXDT detector systems will be based (Figure 5); photos showing the APD/scintillator assembly from a 2014 HAXDT detector and a new, unassembled CsI(Tl) scintillator crystal that will be used in the 2015 detectors (Figure 6); a photo of the NovAtel OEMStar GPS receiver (Figure 7); a photo of the Microsemi Quantum SA.45s CSAC (Figure 8); a photo of the VectorNav VN-100 IMU (Figure 9); a photo of the flight computer attached to the power and interface board from the 2014 HAXDT payload (Figure 10); a photo and mechanical drawing of the NavCom GNSS receiver and antenna (Figures 11–12); photos of the GoPro HERO3+ camera and servo mount (Figure 13); a model of the full 2015 HAXDT payload assembled on the HASP payload plate (Figure 14); mechanical drawings of the bottom plate, side panels, and edge rails of the 3U CubeSat structure (Figures 15–17); and the footprint of the 2015 HAXDT payload on the HASP payload plate (Figure 18).

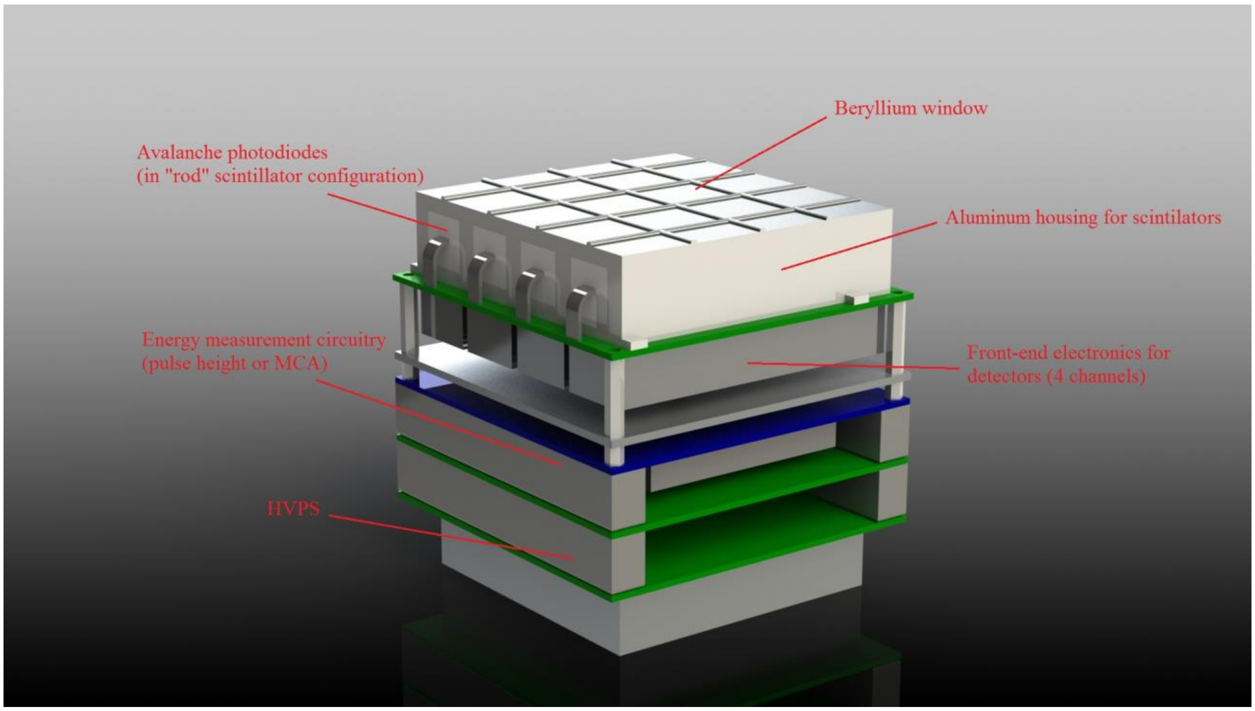

Figure 5. The full detector systems proposed for the GLINT CubeSat demonstration mission. The 2015 HAXDT detector systems will be very similar, although the scintillators may be used in the paddle configuration rather than the rod configuration. With this change, the APDs would be mounted underneath the scintillators, directly on the front-end electronics board, rather than on the side of the detector assembly.

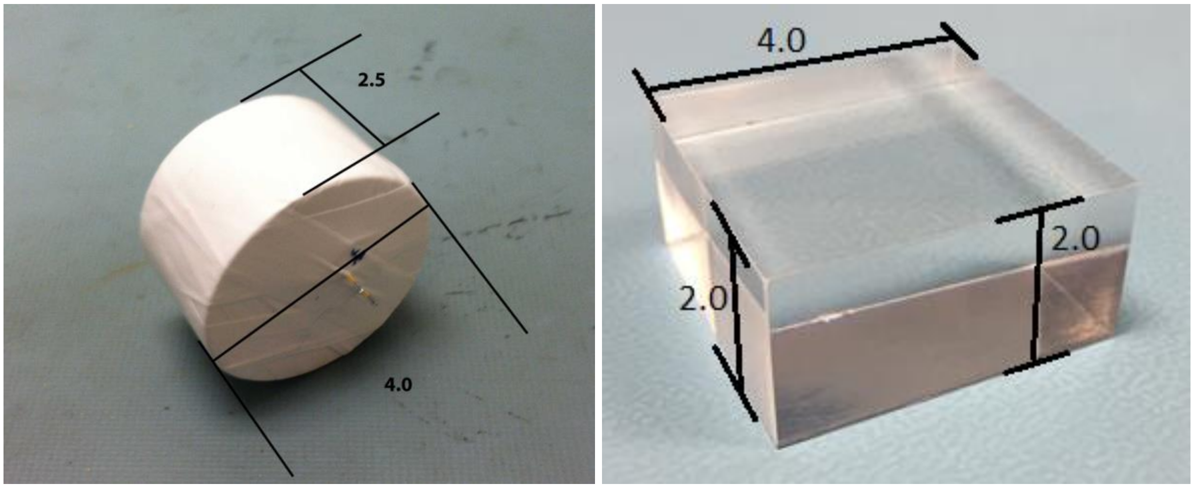

Figure 6. (Left) A cylindrical plastic scintillator from the 2012–2014 HAXDT detector systems, assembled with the APD and PTFE tape wrapping. (Right) A paddle-configuration CsI(Tl) scintillator crystal for the 2015 HAXDT payload, prior to assembly. The 2015 HAXDT detector systems will consist of four of these CsI(Tl) crystals. Dimensions are shown in centimeters.

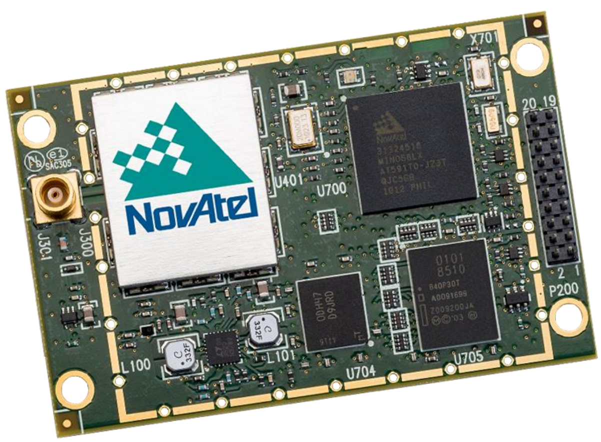

Figure 7. The NovAtel OEMStar GPS receiver. The OEMStar measures 4.6 cm x 7.1 cm.

Figure 8. The Microsemi (formerly Symmetricom) Quantum SA.45s chip-scale atomic clock. The SA.45s measures 3.5 cm x 4.1 cm x 1.1 cm.

Figure 9. The VectorNav VN-100 Rugged IMU. The VN-100 measures 3.6 cm x 3.3 cm x 0.9 cm.

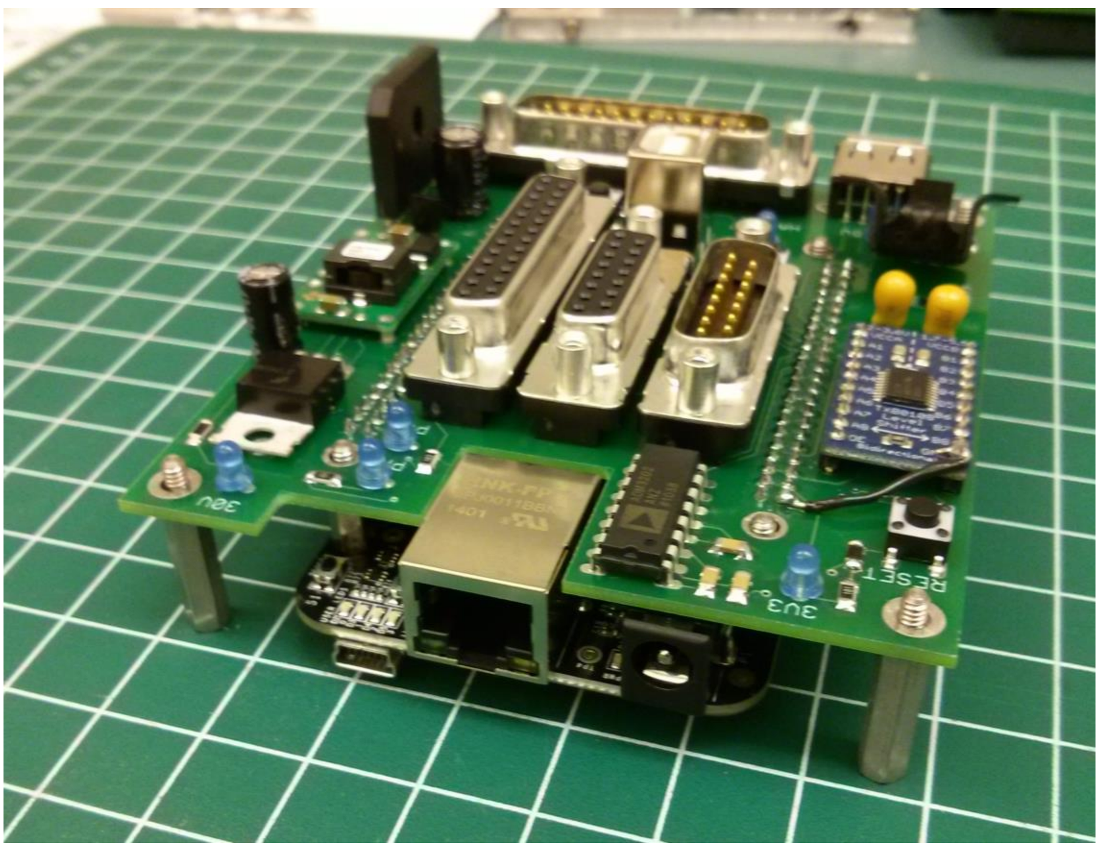

Figure 10. The flight computer (BeagleBone Black) mounted underneath the power and interface board from the 2014 HAXDT payload. The 2015 payload will likely incorporate a similar design into a new form factor better suited for the CubeSat structure.

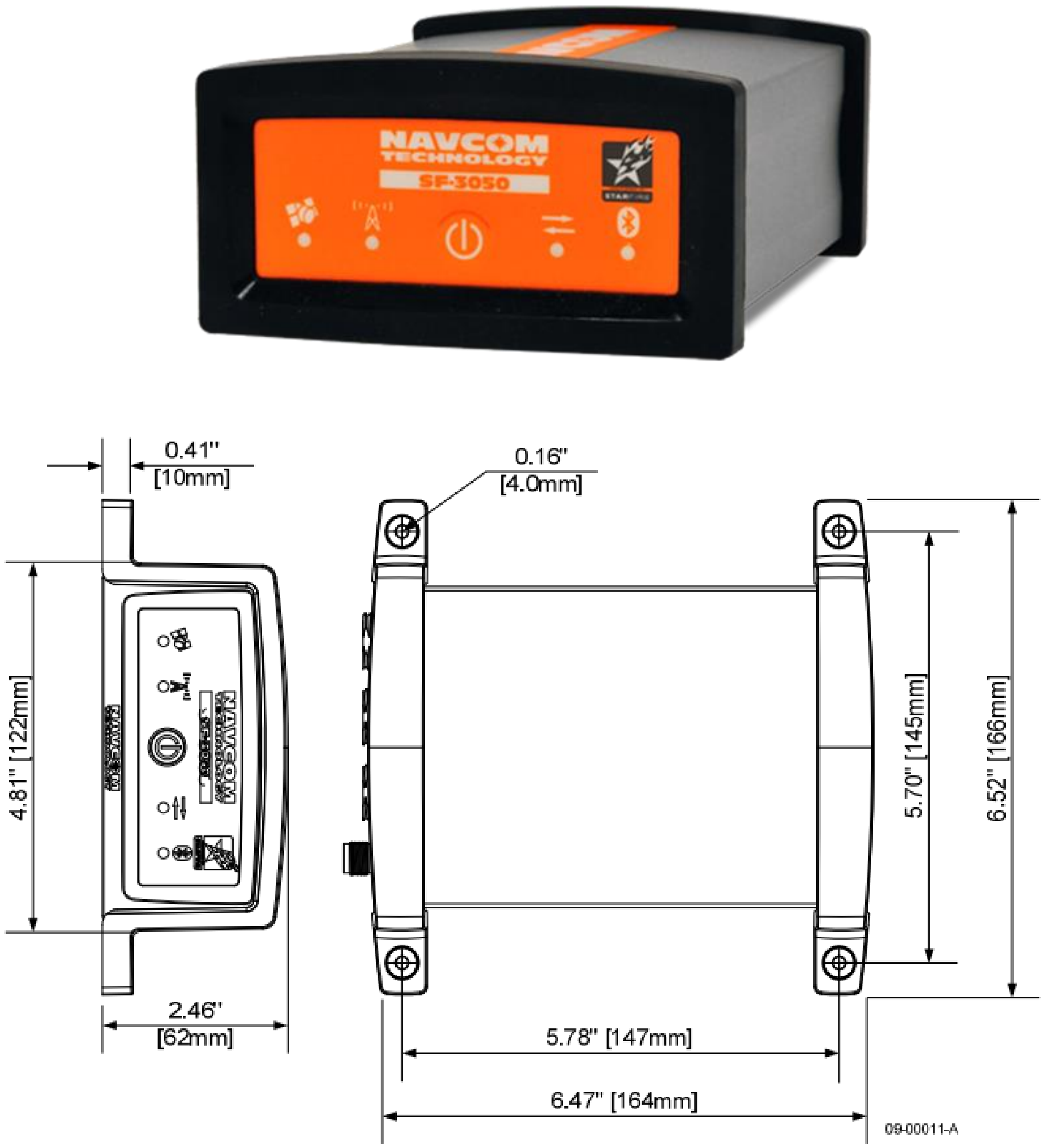

Figure 11. The NavCom SF-3050 GNSS receiver. Dimensions of the receiver are shown in the mechanical drawing (bottom) in inches and millimetres.

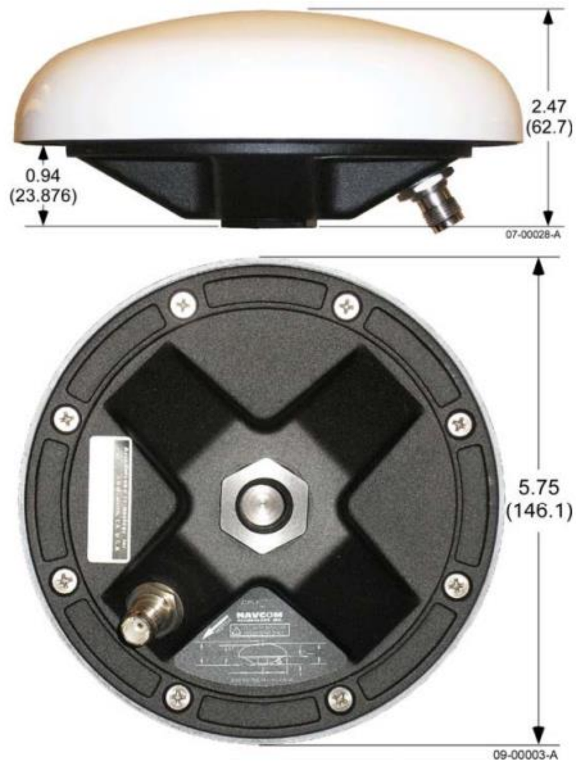

Figure 12. The NavCom GNSS antenna. Dimensions are shown in inches (millimeters).

Figure 13. (Left) The GoPro HERO3+ WiFi-enabled camera for the video downlinking system. (Right) The servo mount for the GoPro. The GoPro measures 5.9 cm x 4.1 cm x 2.8 cm.

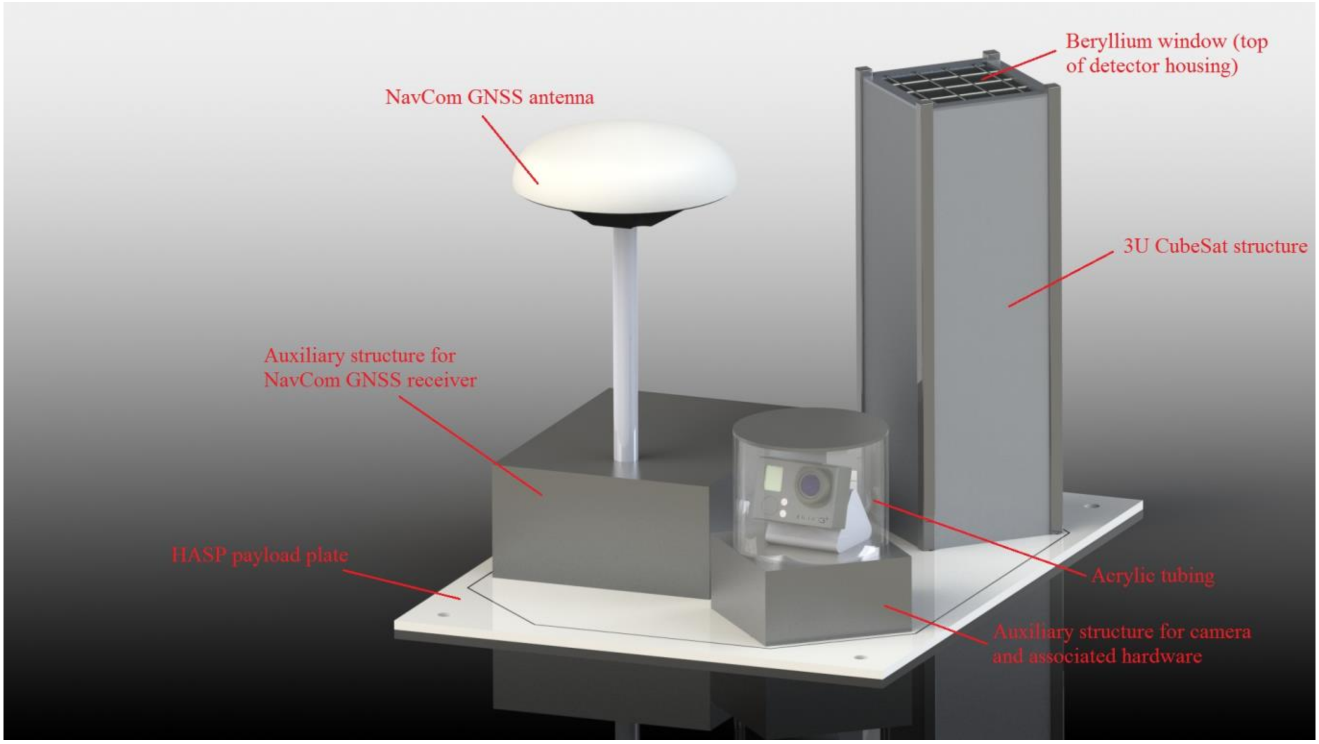

Figure 14. The full 2015 HAXDT payload in its preliminary mounting configuration on the HASP payload plate. Note that because the entire zenith end of the 3U CubeSat structure will be occupied by the detector systems, the GPS antenna for the OEMStar must be placed elsewhere. The exact placement has yet to be determined, and thus this antenna is not shown in the model.

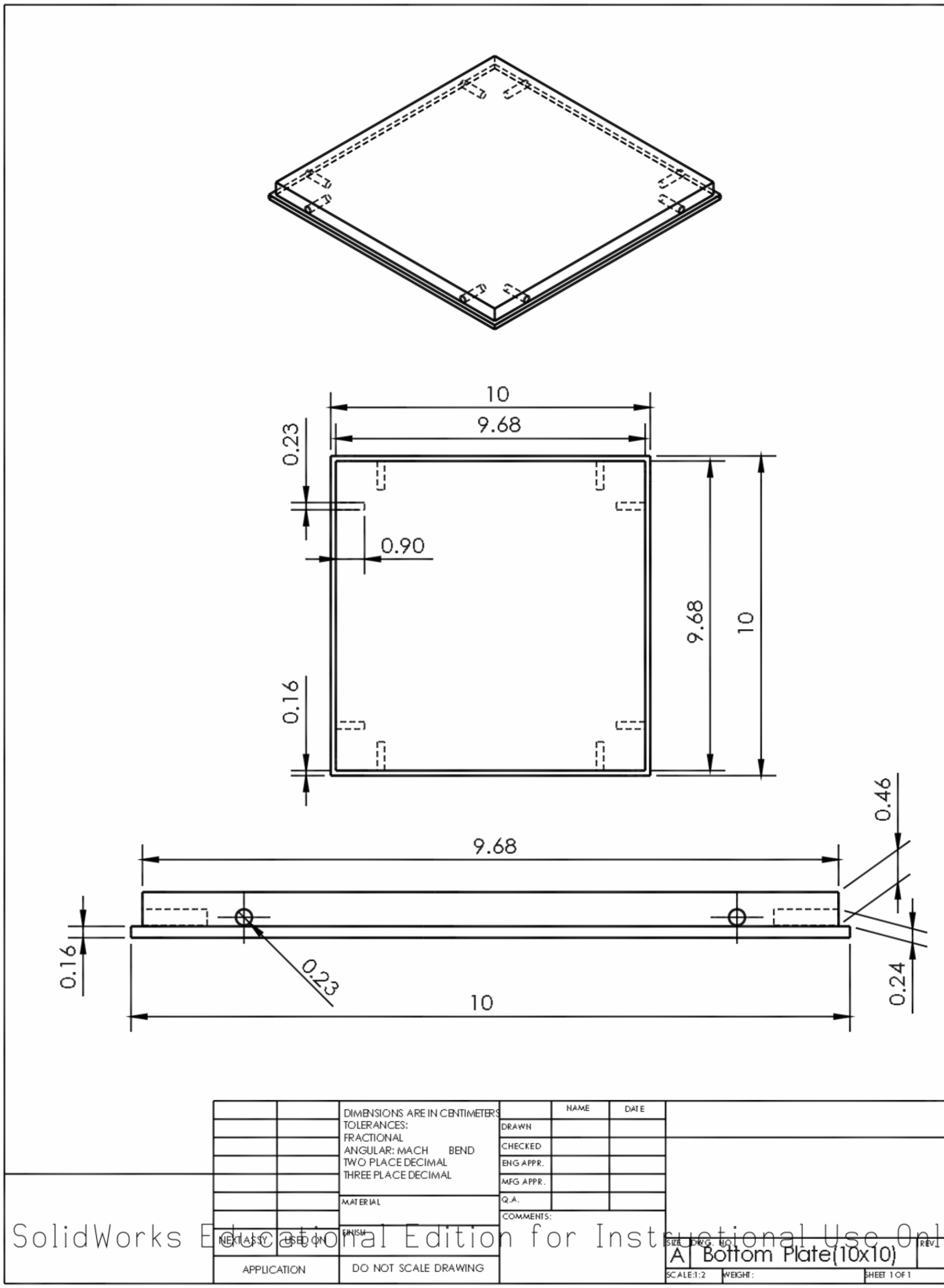

Figure 15. A mechanical drawing of the aluminum bottom plate of the 3U CubeSat structure, with dimensions shown in centimeters. This plate will be securely fastened to the HASP payload plate.

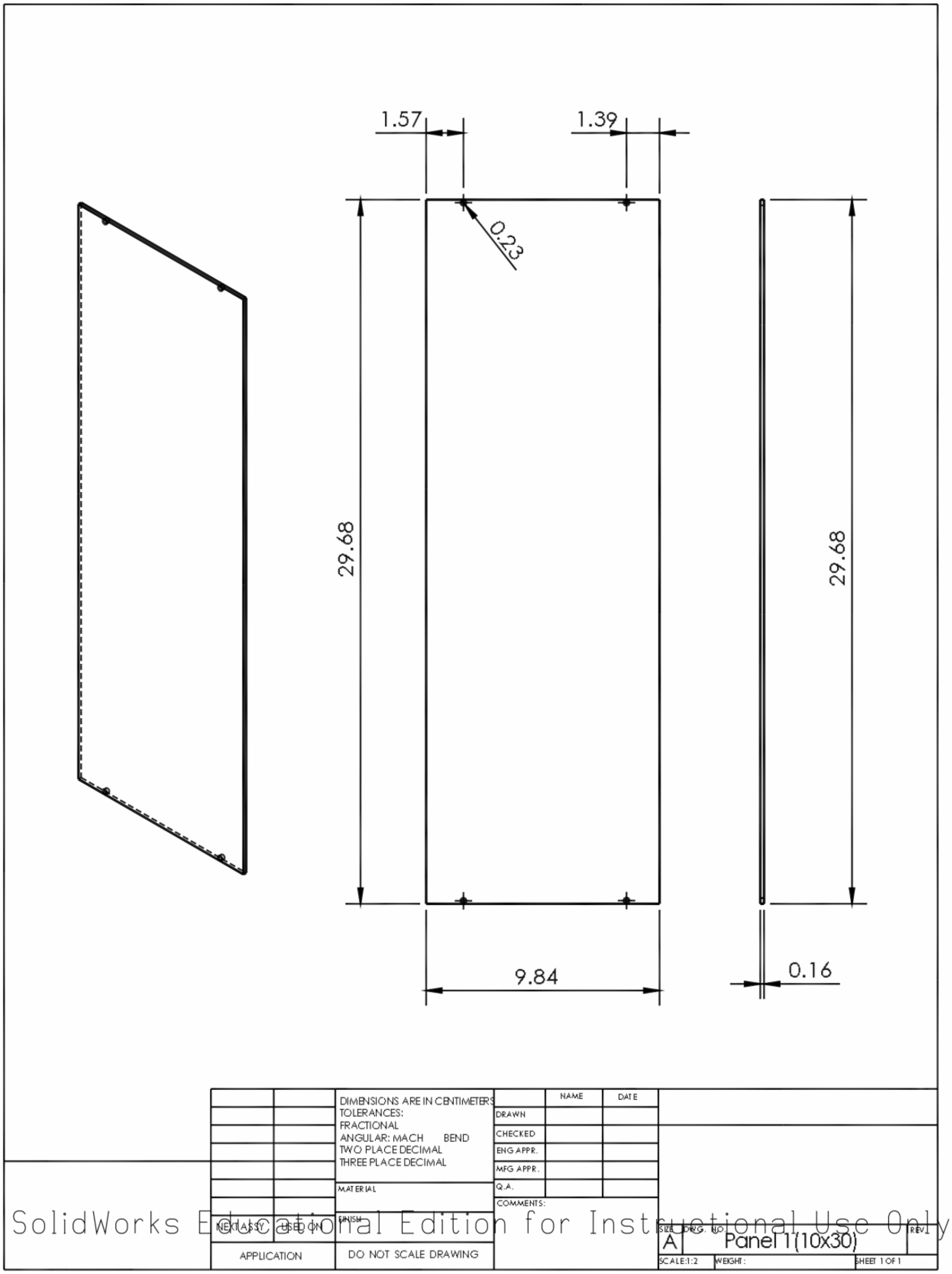

Figure 16. A mechanical drawing of the aluminum side panels of the 3U CubeSat structure, with dimensions in centimeters.

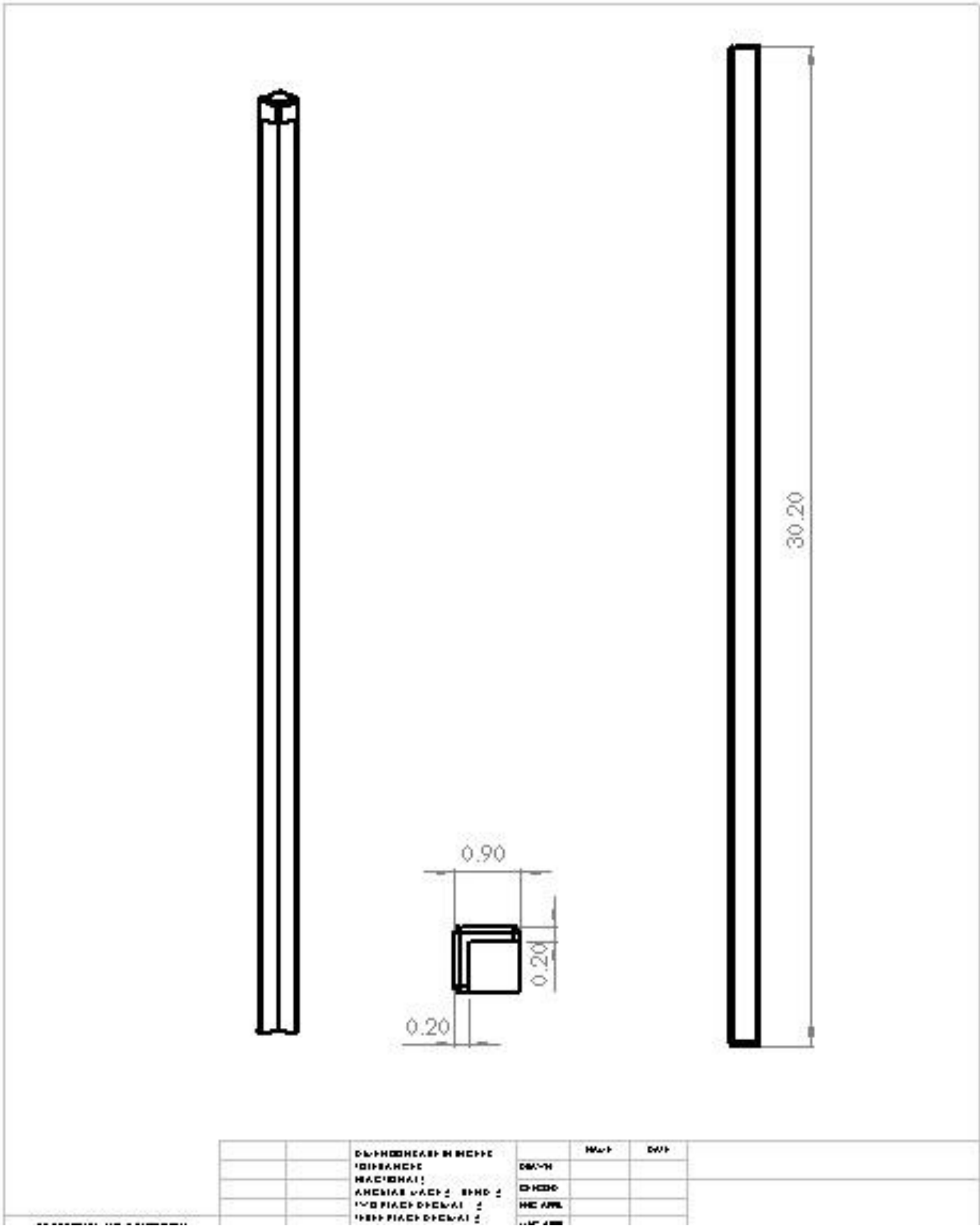

Figure 17. A mechanical drawing of the edge rails used in the 3U CubeSat structure, with dimensions in centimeters.

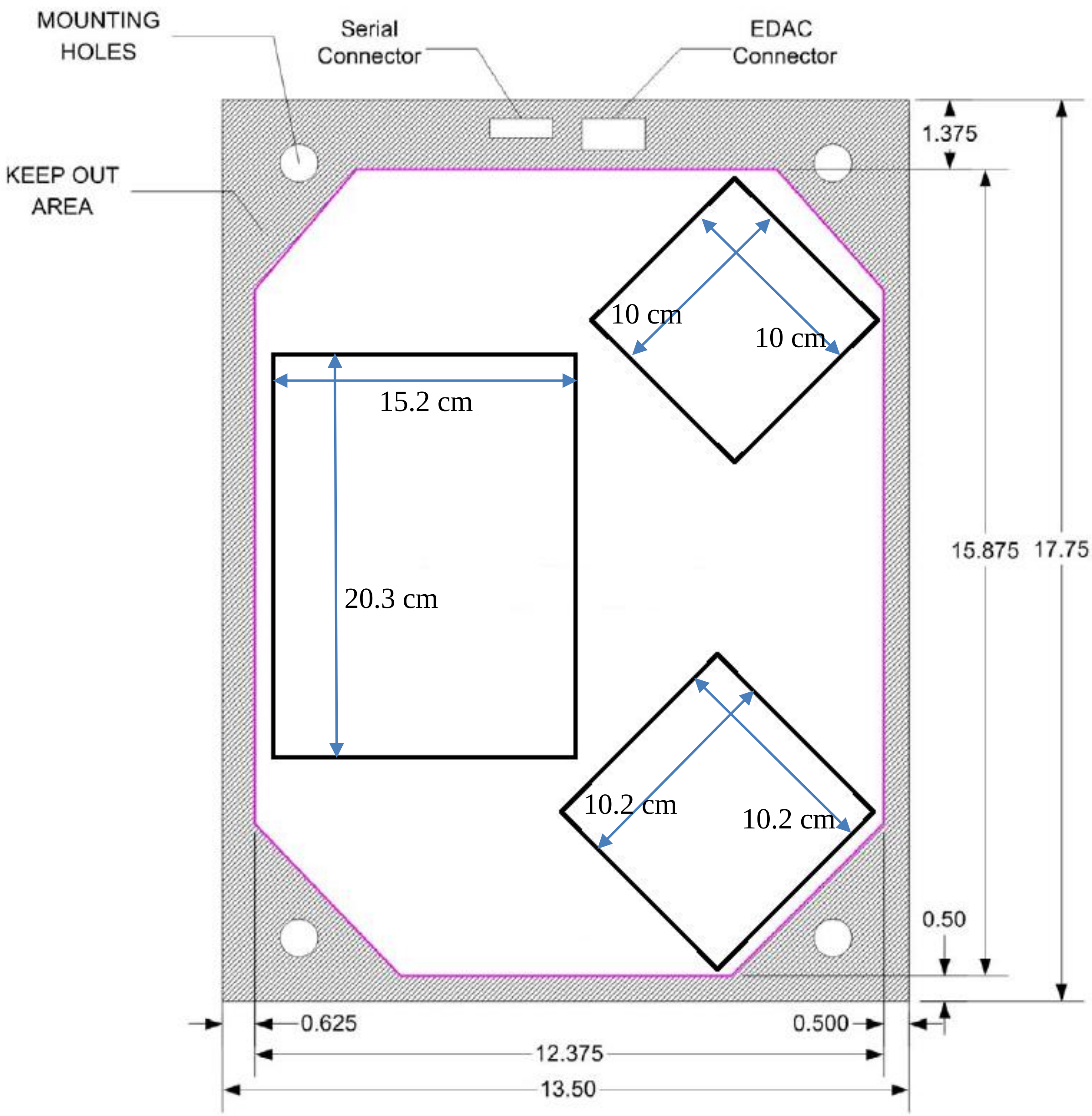

Figure 18. The footprint occupied by the 2015 HAXDT payload on the large HASP payload plate.

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