HASP Student Payload Application for 2014

Payload Title: High Altitude X-ray Detector Testbed

Payload Class: (check one) ☑ Small ☐ Large	Institution: University of Minnesota	Submit Date: December 20, 2013

Project Abstract

The work described in this proposal is motivated by the idea of using celestial X-ray sources such as pulsars as beacons for deep space navigation. The development of a compact X-ray detector system is an enabler of this concept. The engineering objective of the experiment being proposed is to upgrade the compact X-ray detector and its associated hardware that flew on the 2012 HASP mission and was improved for the 2013 HASP mission (though it did not fly due to a launch mishap). The primary upgrade for the 2014 payload is the addition of a second scintillation detector to allow for the detection of coincident photons in a narrow field of view. The energies of the photon events will also be recorded by the payload. 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 characterize the cosmic ray background, and thus the signal-to-noise ratio (SNR) as seen by such small detectors in these separate energy bands. The educational objective is to provide students with a hands-on experience in designing and testing of avionics systems. The 2014 HAXDT will be designed to conform to a 3-U CubeSat infrastructure with a 3000 cm^3 internal payload volume and will weigh less than 3 kg. Current interface requirements include less than 15 watts of power, and 440 bps of downlink bandwidth.

Team Name: University of Minnesota	Team or Project Website: https://wiki.umn.edu/HASP/WebHome

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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 and 2013 HASP missions. Such compact X-ray detectors are being developed for use as navigation sensors for future deep space missions.

Due to a mishap during launch, the payload built for the 2013 HASP mission was not able to collect flight data. However, the payload successfully collected data during rigorous environmental testing at the HASP integration.

The payload flown on the 2012 HASP mission collected a time history of photon events counted by an X-ray detector (scintillation detector). However, the detector system was incapable of measuring the energies of the photons that created the scintillation events. Thus, the engineering objective of the 2013 HASP mission payload was to upgrade the compact X-ray detector along with associated hardware, electronics, and software that flew on the 2012 HASP mission to allow recording of both the time and energy of the photon events. Although the payload did not have the opportunity to perform a successful mission, the design goals of the payload were met, and it was successfully able to record the energy levels of photon events in addition to the data gathered by the 2012 iteration. As such, the payload that will fly on the 2014 HASP mission will have several upgrades from the 2013 payload. These upgrades include the following: the replacement of the current MPC5200B-based flight computer with a Raspberry Pi; the addition of a second scintillation detector to the two-channel nuclear pulse-shaping circuit (detector board) provided by Lockheed Martin's Advanced Technology Center in Palo Alto, CA; the replacement of the Novatel OEMV-3 GPS receiver which was damaged during the 2013 launch; and finally, the addition of a downward-looking camera to provide additional attitude determination data.

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. This will allow correlation of photon flux with celestial bodies capable of emitting such high-energy cosmic rays. Another scientific goal is to characterize the cosmic ray background, and thus the signal-to-noise ratio (SNR) as seen by such small detectors in these separate energy bands. Further, the second detector is being added to investigate a proposed vetoing scheme by which the field of view of the experiment can be narrowed and the accuracy of the experimental results more readily verified by focusing primarily on coincident photon events between the two detectors. This will provide some directionality to the detector and eliminate the need for bulky and heavy lead shielding as used in the 2013 payload. Pinpointing the direction of arrival of detected photons is critical to the use of such detectors for navigation, and is thus an important goal of the HAXDT project.

1.1 Background

The work described in this proposal is motivated by the idea of using celestial X-ray sources such as pulsars as beacons 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.

1.2 Technical Challenge

Pulsars are excellent candidates for use as XNAV beacons. This is because their signals can be used to provide time, range, and phase measurements — key parameters for navigation. It has been demonstrated that the stability of pulsar spin rates compares well to atomic clocks [4]. Furthermore, X-ray signals from pulsars have identifying profiles [5]. However, because the distance to even the closest pulsar is on the order of parsecs, the signal-to-noise ratio (SNR) of the received X-ray signals is small. The low SNR is due to, in part, the background X-ray noise in space. One current method for detection of these low SNR signals relies on counting a bin number of photons in some known time interval and measuring the energy released by the photons upon striking a detector. In this manner, specific peaks are recorded according to the pulsar's wavelength, thus allowing the source pulsar to be identified. This implies that accurate range or phase measurements require large X-ray detector areas, long signal collection times, or both. For example, it has been demonstrated that detectors with areas larger than 1 m^2 provide position accuracies that are acceptable for many space-based applications [4]. While detectors of this size can be used on larger space vehicles, they are impractical for smaller ones. The work described in this proposal attempts to characterize the background noise at different energy levels as seen a by small photon detector at altitudes above 30 km, and add to the detector's flight heritage.

1.3 Hypothesis

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]. Further, the sensitivity of the detectors on the HAXDT payload precludes the accurate detection of photons in this energy band. The peak sensitivity of the detectors is in the range of 100 keV to 5 MeV, corresponding primarily to gamma rays. Such energies may be unsuitable for navigation algorithms, but detection of photons at these energy levels still allows analysis of the SNR for small detectors to be performed. The ability of a small detector system to associate an energy level with a detected cosmic ray event will allow characterization of the SNR over multiple energy bands while also allowing the data to be examined for possible high-energy celestial sources.

1.4 Payload Systems and Principle of Operation

A high-level diagram of the payload's systems is shown in Figure 1 below. The interior components consist of a two-channel detector board, two detector assemblies and their housings, pulse height analysis circuitry, a GPS receiver, a power circuit with an attached Analog Devices inertial measurement unit (IMU), and a flight computer affixed to a daughterboard. The payload will also include a small camera, which will take and log data independently of the flight computer. These components are shown in Figures 2–9. Power is provided by HASP and is regulated to +12 VDC to power all payload systems as seen in Figure 10. The power circuit also provides protection from reverse polarity and limits the current draw to 495mA to prevent inrush current spikes. The schematic for this circuit is shown in Figure 12.

1.4.1 Sensor Payload

Each detector assembly is seated in an aluminum housing (Figure 2) and consists of an avalanche photodiode (APD) affixed to a plastic organic scintillator with optical grease. The assembly is then wrapped in polytetraflouroethylene (PTFE) tape (Figure 3). Light flashes generated by high-energy particle interactions with the scintillator are shaped into voltage pulses by the two-channel detector board and are, thus, detected as photon strikes that are time-tagged by the flight computer. The voltages are also fed through custom-built pulse height analysis circuitry which measure the peak levels, and thus the energy of each photon strike. This information will be stored along with the time-tagged photon strikes in onboard flash memory in order to perform analysis on multiple detected energy bands.

A compact camera will also be used for a vision-based navigation and attitude determination system. Using the Chameleon camera from Point Grey Research (Figure 9), the orientation of the payload will be determined by taking successive pictures throughout the flight. This, in turn, will help with calibrating the orientation of the prototype X-ray detector, advancing the overall goal of X-ray navigation. Before flight, the camera will need to be calibrated in the lab by placing it at precisely known location where pictures will be taken. After several tests, these pictures will be used to find focal length, lens distortions, skew factors, and scaling factors which will help eliminate error in the data during the flight. Algorithms, which have been developed by Ph.D. students under the supervision of Dr. Demoz Gebre-Eqziabher, will then be modified for attitude determination from these measurements. Original algorithms will be written, based on PnP algorithms, in order to determine the attitude from pixel measurements. These will then be tested to ensure accuracy before being integrated into the payload and prepared for flight testing.

1.4.2 Structure

The structure is composed of 6061-T6 aluminum that is in a 3U-CubeSat formation. One side of the aluminum walls is polished to assist in thermal protection as outlines below. There are four wall panels, a top plate, and a bottom plate (see Figures 12–18) all attached to a structural skeleton to increase the payload's strength and to give easier access to the components inside. These are all attached together with size #4-40 self-locking 18-8 stainless steel socket head cap screws while the exception of the bottom plate which is attached to the HASP Payload Mounting Plate with 1.25" long ATSM A307 ¼"-20 bolts. The exterior walls will be coated with a white spray-on epoxy. 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.

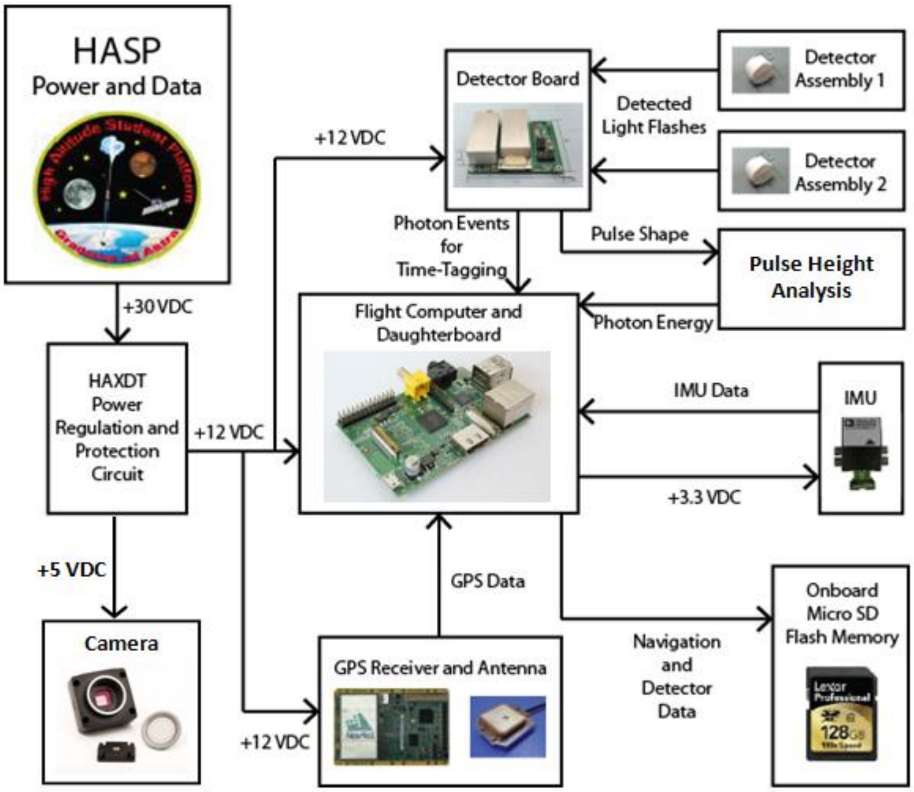

Figure 1. High-level HAXDT payload system diagram.

1.4.3 Computer and Data Logger

The new flight computer is a Broadcom BCM2835 SoC (Raspberry Pi) which will run flight code written in the C language, operating on a real-time Linux kernel. The flight code, based off of the open source code used by the UAV Research Group at University of Minnesota, has been rewritten to perform attitude determination while collecting data from two X-ray detectors. GPS signals will be provided using a new receiver: either a Novatel OEMStar or a uBlox LEA-6-T, both of which are functionally similar to the Novatel OEMV-3 used for previous missions, yet much more affordable. The new receivers being considered also feature a smaller form factor and lower power requirements compared to the Novatel OEMV-3. The IMU is an Analog Devices ADIS16405 that provides angular rates and accelerations as well as magnetic field and temperature data. A custom-designed daughterboard handles the hardware interface to the flight computer. An accurate navigation solution is obtained by combining the IMU data with the GPS position estimate. The data generated by the attitude determination system is placed in onboard storage throughout the flight for post processing.

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. Therefore, a single power up command will be sufficient for payload operation. All data will be stored onboard 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 off and on the payload will be made.

An active thermal protection system may be implemented to prevent the temperature of the electrical components in the payload from dropping below their specified minima. Such a system would use an infrared radiator to warm the components during the ascent, when atmospheric temperatures can drop below −60 °C. The heater would then switch off to prevent overheating as the payload is warmed by the sun during float. The development and inclusion of this system is only a secondary goal for the 2014 payload. It would serve as a preventative measure to decrease the likelihood of GPS dropouts and flight computer malfunctions; however, based on the performance of the 2012 payload on the HASP flight and the 2013 payload during environmental testing, it is clear that the payload can still perform all necessary basic functions without any active thermal protection.

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's engineering responsibilities will focus on the energy detection portion of the X-ray detector system and the operation of the attitude and navigation sensors. Several undergraduate students who worked on the 2013 payload will continue their contributions for the 2014 project cycle. John Jackson will assist on the energy detection portion of the detector system as well as the flight computer and software development. Andrew Mahon will take the lead on the integration of the second X-ray detector and the development of the vetoing scheme for non-coincident photon events. Haley Rorvick will lead the design and fabrication of the payload structure and be responsible for the camera-based attitude determination system. Josiah DeLange will work on the flight computer and power systems as well as the flight software. Alec Forsman will assist in payload fabrication and the integration of the new electrical hardware and sensors. Seth Merrifield will assist in the integration of new electrical hardware and be responsible for the development of thermal monitoring and protection systems. Mr. Mahon and Ms. Rorvick will be compensated for their work with the team through outside funding provided by the University of Minnesota's Undergraduate Research Opportunities Program (UROP). 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.

Dr. James Flaten is supervisor for the University of Minnesota ballooning team and provides expert advice in balloon flight operations. Dr. Suneel Sheikh is an expert in X-ray navigation and provides ongoing consultation in the development of this payload system. 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. 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 no 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 2014	**Description of Work**
January	Additional hardware acquisition. Undergraduate recruitment and training. **Testing and calibration of new detector components. Testing of new GPS receiver.**
February–March	**Structure development.** Testing of new flight computer with existing flight software.
March–April	**Design of flight configuration. Final dimensioned mechanical drawings.** Power and interface systems development. Camera testing and integration.
April 25	**Preliminary PSIP document deadline.**
April–May	Full systems integration and flight software development. **Fabrication of payload structure.**
June	**Final assembly and testing of payload.**
June 27	**Final PSIP document deadline.**
July	Finalize flight operations plan. Verify all systems go for launch.
July 31	**Final FLOP document deadline.**
August 4–8	**Student payload integration.**
August	Correct unforeseen issues found during payload integration if needed.
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 2015 application.**

Table 2. Preliminary 2014 HASP timeline.

3. Payload Specifications

The payload is designed to conform to a CubeSat generic structure, based on one or more cubes with internal dimensions of 10 cm x 10 cm x 10 cm, thus having a 100 cm^2 footprint on the HASP mounting plate as shown in Figure 19. A single cube is known as a 1-U, or unit volume, configuration. The 2013 HAXDT payload is anticipated to be in a 3-U configuration. This implies that the payload height will be 30 cm, thus assuring that the payload falls within the HASP height guidelines for the **small payload** classification. The CubeSat infrastructure supports several future envisioned XNAV/HASP missions as well, including onboard X-ray attitude control for detector pointing and X-ray communications (X-COM). It is possible that the footprint may expand to include the entire area available on the HASP mounting plate if upgrades to the detector system require a larger footprint, but the need for such an increased footprint is uncertain at this time.

At this time there are 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 1200 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 440 bps (the 44 byte packet outlined in Table 3 below plus serial framing bits) sent over the

1200 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 accommodate the transmission of data samples taken from the IMU and the X-ray detectors as well 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 data record
3–10	GPSec	Milliseconds since beginning of GPS week
11–18	X_Pos	Earth-centered Earth-fixed, x coordinate
19–26	Y_Pos	Earth-centered Earth-fixed, y coordinate
27–34	Z_Pos	Earth-centered Earth-fixed, z coordinate
35–42	Ambient_Temp	Temperature of internal chamber of payload
43–44	Footer	Indicates end of complete data record

Table 3. Anticipated downlink data record.

Both analog channels are expected to be utilized for internal temperature monitoring. One analog line will be used to monitor the temperature of the detector board, and the other analog line will be used to monitor the flight computer’s processor core temperature. If the processor core temperature exceeds 125 °C, then a power off command will be requested to let the processor cool for 15 minutes.

Procedures at integration are anticipated to 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, transmits, 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 10. Voltage will be regulated and distributed according to each system’s power requirements as shown in Figures 10 and 11.

Table 4 below outlines the power and mass budgets for the payload components. The flight computer, daughterboard, and power circuit will again be bundled together as in figures 7 and 8, so their mass and power requirements have been combined and reported as such. There will be a second X-ray detector added to the system for the 2014 payload, and thus the full system will consist of two detector housings, two scintillators, two APD’s, and the two-channel detector board. The combined mass and power requirements of the two detectors are reported together. The addition of the camera is also noted. Structural components include the payload walls, mounting hardware, and GPS antenna embedded in the top plate (with care taken not to exceed the 30 cm restriction). Furthermore, the CubeSat sizing guidelines may be abandoned in favor of utilizing the full space available on the HASP payload plate, but only if this is necessary to allow all of the internal components to fit inside the payload. The large uncertainty in structural mass is due to this, and will allow us to explore these options. The mass and power requirements for a potential thermal protection system are unknown, and allowed a large amount of uncertainty compared to other known hardware components. Regardless of the design changes which may yet be made (modifying the payload sizing, adding thermal protection, etc.), the mass and power specifications of the payload will remain within the limits of +30 VDC at 0.5 amps (15 Watts) and 3 kg, respectively, for the small payload classification.

Component	Mass (g)	Mass uncertainty (g)	Power (W)	Power uncertainty (W)
Flight computer, daughterboard, and power circuitry	200	20	2.0	0.2
X-ray detector system	700	40	1.0	0.2
IMU	20	5	0.5	0.2
GPS Receiver	30	10	0.5	0.1
Camera	40	5	2.0	0.2
Thermal Protection	100	25	5.0	1.0
Structure	1000	500	-	-
Total	2090	605	11.0	1.9

Table 4. Preliminary mass and power budget.

3.2 Payload Location and Orientation

The majority of the experimental goals are independent of the physical location on the HASP gondola. The only exception to this would be that a camera is being added to the bottom of the payload to determine the payload's attitude which will verify the directionality of the pulsars. HAXDT successfully flew on the 2012 HASP mission in payload position 3 (and was mounted in this position for the 2013 flight), which is suitable for the 2014 flight as well (see Figure 20). A position on the gondola outriggers is necessary so the camera can see out of the bottom. The payload mounting does not depend on orientation as the detectors are vertically mounted and are in-line with the camera mounted on the bottom of the payload. Modifications to the HASP mounting plate are shown in Figure 21.

4. Preliminary Drawings

The figures below include the following: mechanical drawing of the detector housing (Figure 2); APD/scintillator detector assembly (Figure 3); two-channel detector board (Figure 4); GPS receiver (Figure 5); GPS antenna (Figure 6); power circuit and IMU (Figure 7); flight computer and daughterboard (Figure 8); camera (Figure 9); schematic of HAXDT power system and HASP interface (Figure 10); circuit diagram of the power circuit (Figure 11); 3-D rendering of the 2.5-U HAXDT configuration (Figure 12); mechanical drawings of the 2.5-U HAXDT configuration (Figures 13–18); payload mounting plate footprint (Figure 19); desired payload location and orientation (Figure 20), and lastly, anticipated modifications to the payload mounting plate (Figure 21). Please note that the 3-U HAXDT payload walls will be 5cm (about 2in) taller than depicted in Figures 14–17.

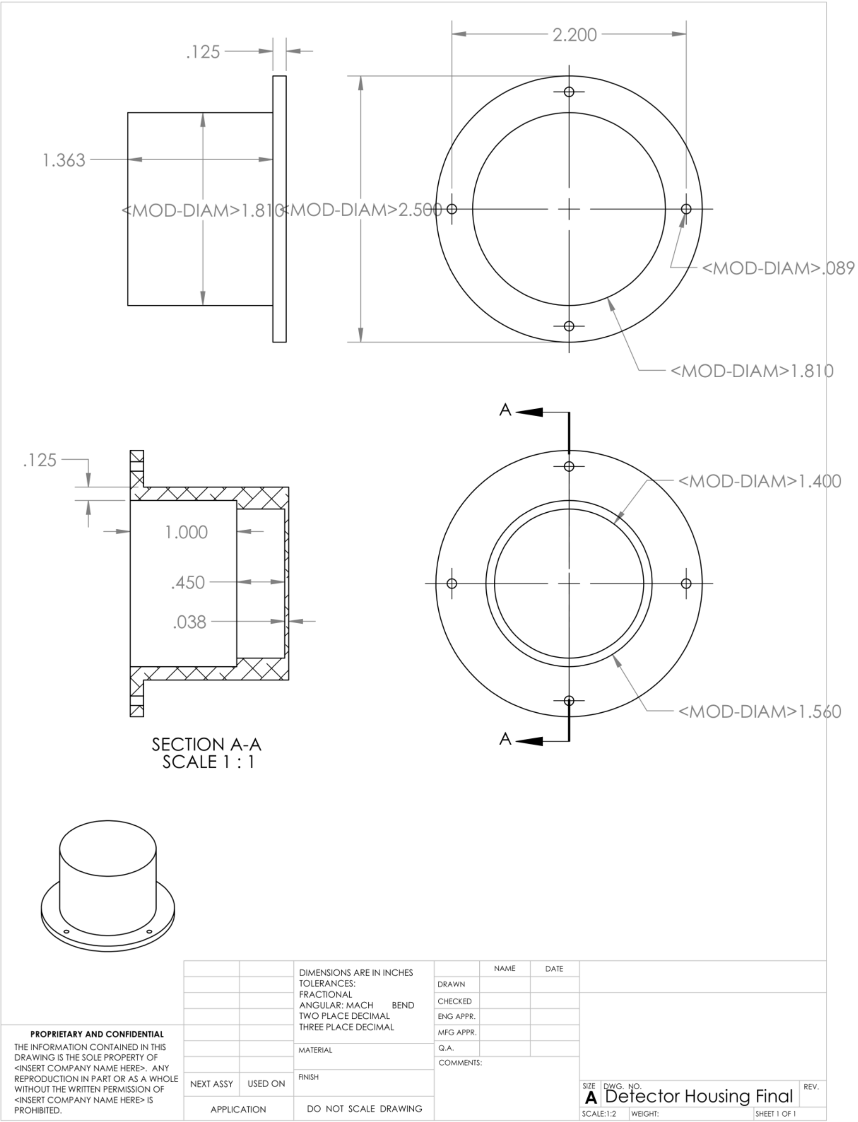

Figure 2. Mechanical drawing of detector housing with dimensions in inches. This housing attaches to the top plate of the HAXDT structure (Figure 18).

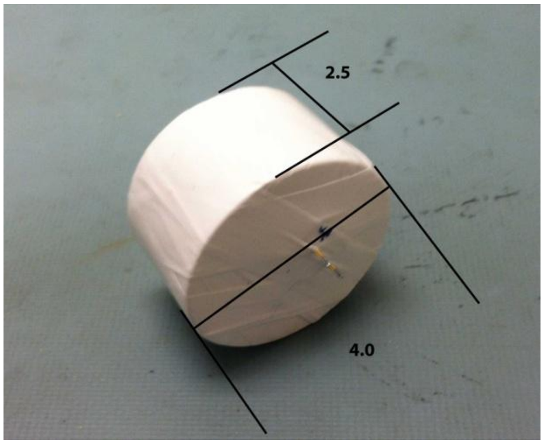

Figure 3. Detector assembly (Si APD affixed to scintillator and wrapped with PTFE tape) with dimensions in centimeters.

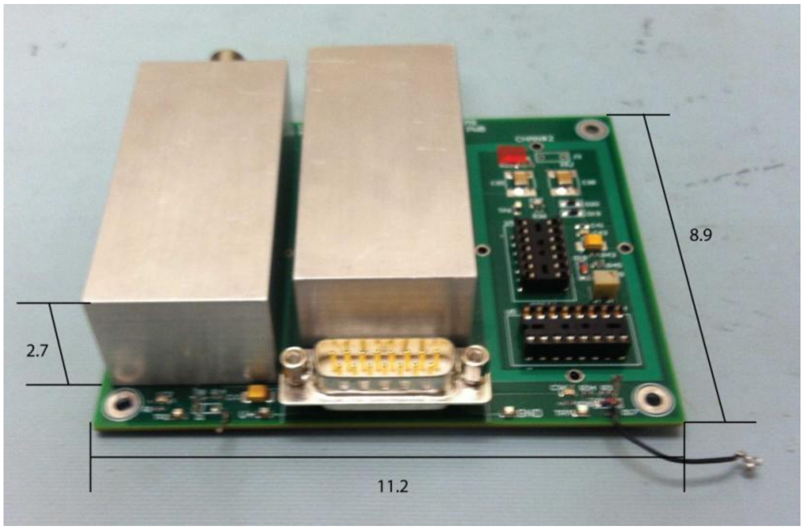

Figure 4. Picture of detector board with dimensions in centimeters. Note that the second channel (right side) will be used and shielded in the same manner as the channel on the left side.

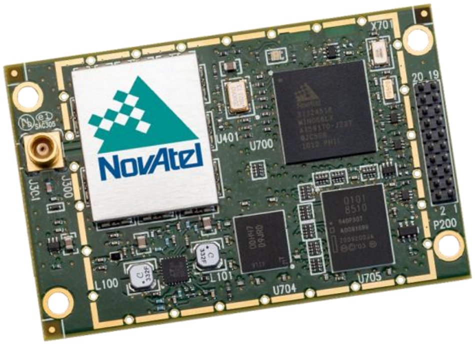

Figure 5. Picture of Novatel OEMStar GPS receiver, the likely replacement for the damaged Novatel OEMV-3. The OEMStar measures 7.1 cm by 4.6 cm.

Figure 6. Picture of San Jose Technology, Inc. SA60 GPS antenna, which attaches to the outside of the top plate as seen in Figure 12.

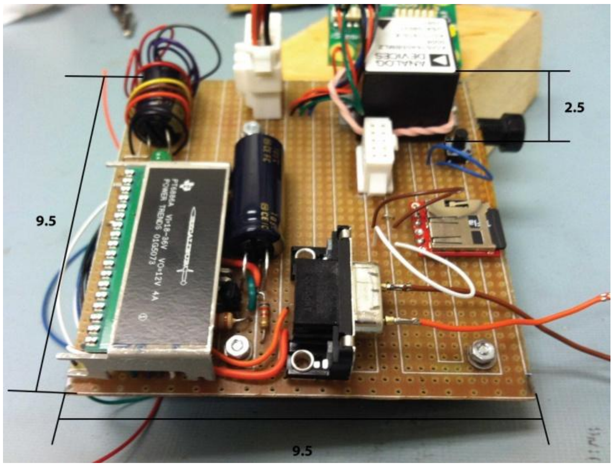

Figure 7. Picture of power circuit and Analog Devices IMU with dimensions in centimeters. This board is bundled with the daughterboard and flight computer as seen in Figure 8. Similar circuitry will be recreated on a new board for the 2014 payload.

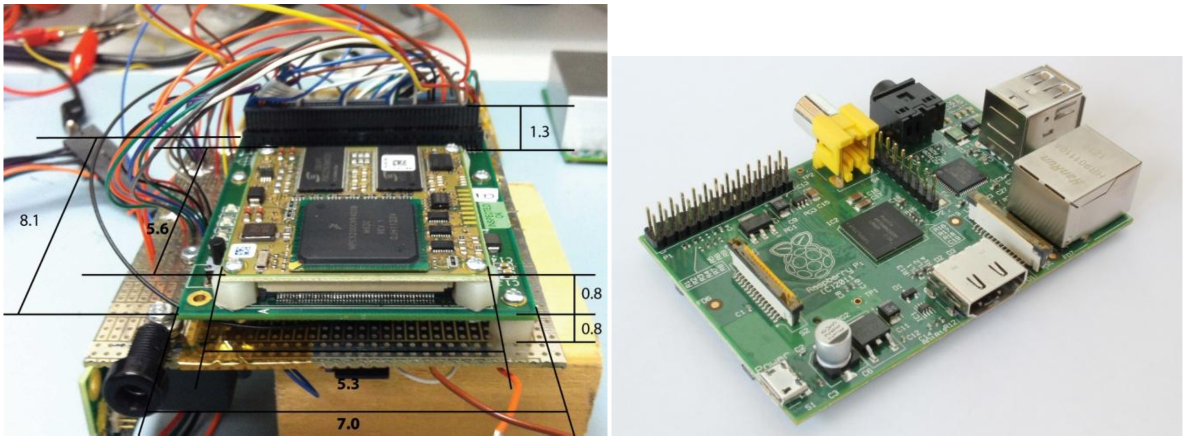

Figure 8. (Left) Picture of daughterboard (green board) and flight computer (tan board) from the 2013 payload with dimensions in centimeters. (Right) Picture of a Raspberry Pi, the new flight computer platform which will be used on the 2014 payload. The Raspberry Pi measures 8.6 cm by 5.6 cm. A new daughterboard will be developed to allow current hardware to interface with the Raspberry Pi.

Figure 9. The Chameleon camera from Point Grey Research. The camera measures 4.4 cm by 4.1 cm by 2.6 cm.

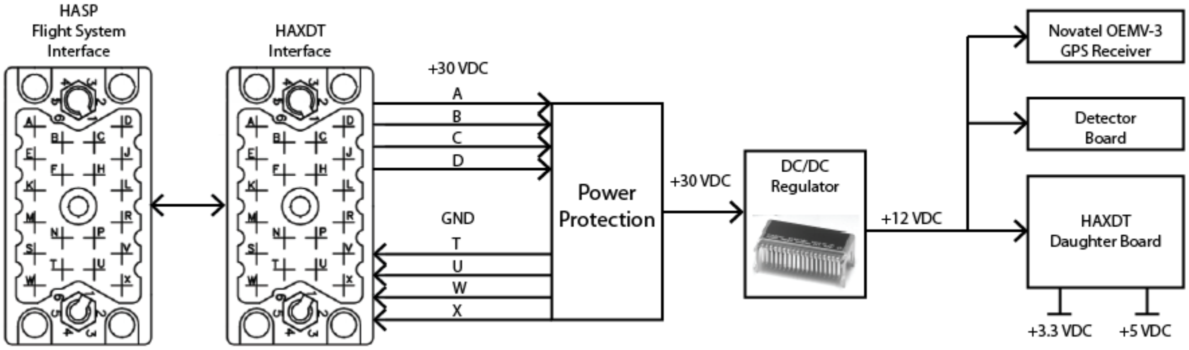

Figure 10. Schematic of HASP EDAC516 connector interface with the HAXDT payload power system.

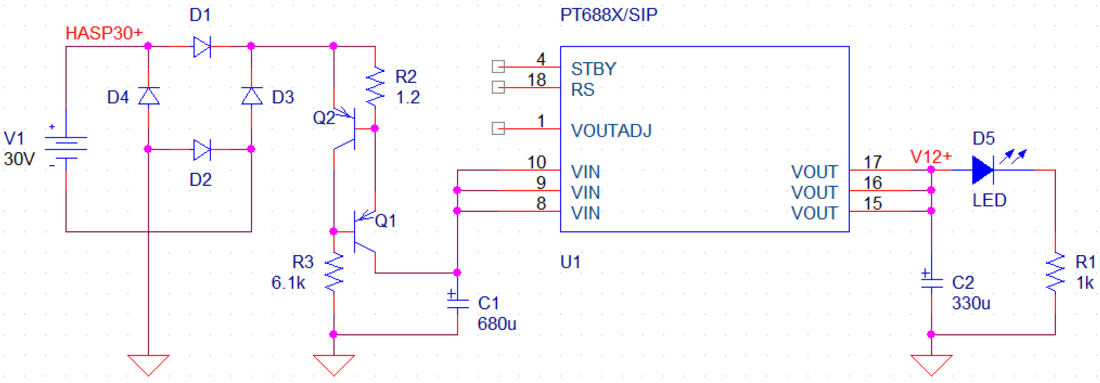

Figure 11. Power regulation and protection circuit diagram.

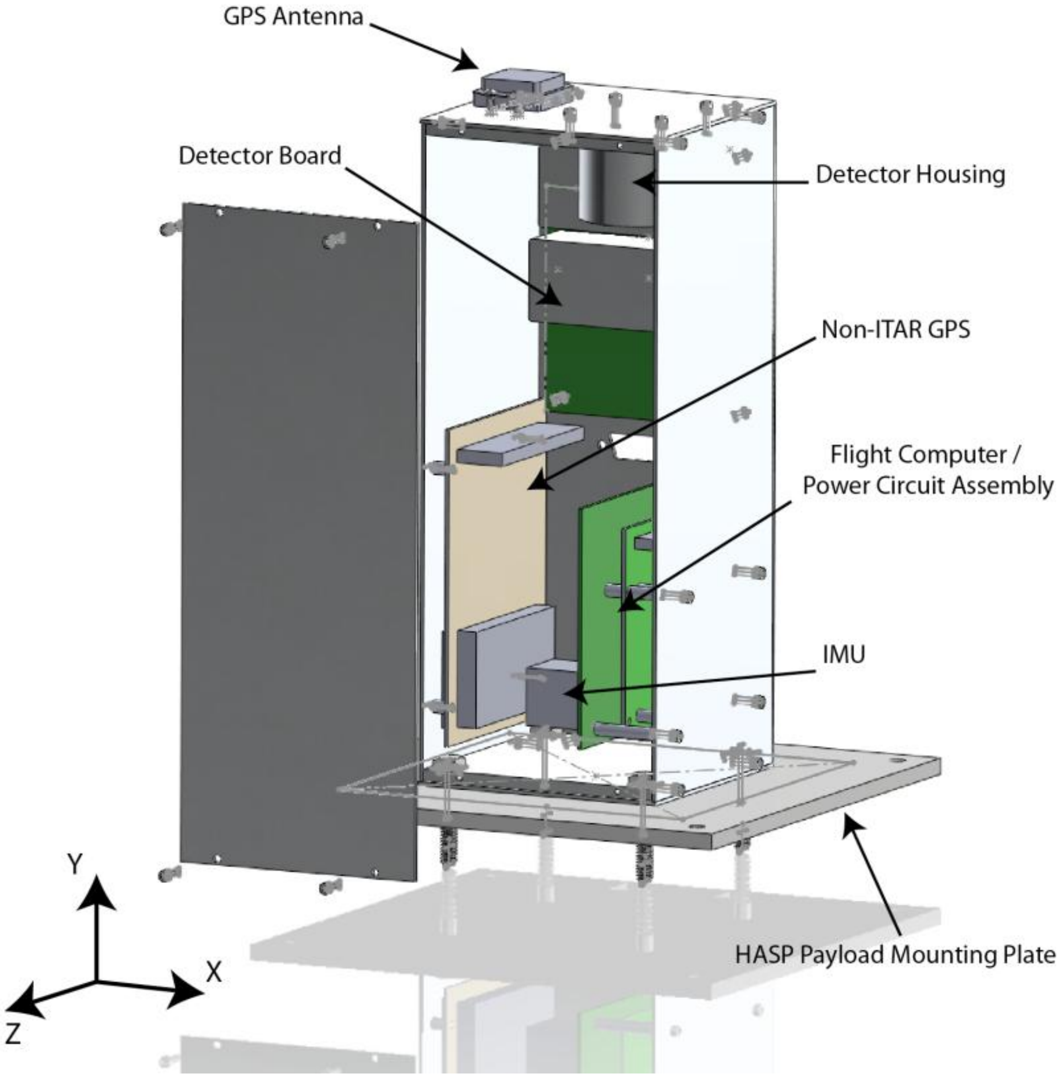

Figure 12. 3-D rendering of a 2.5-U HAXDT configuration. This configuration successfully flew on the 2012 HASP mission.

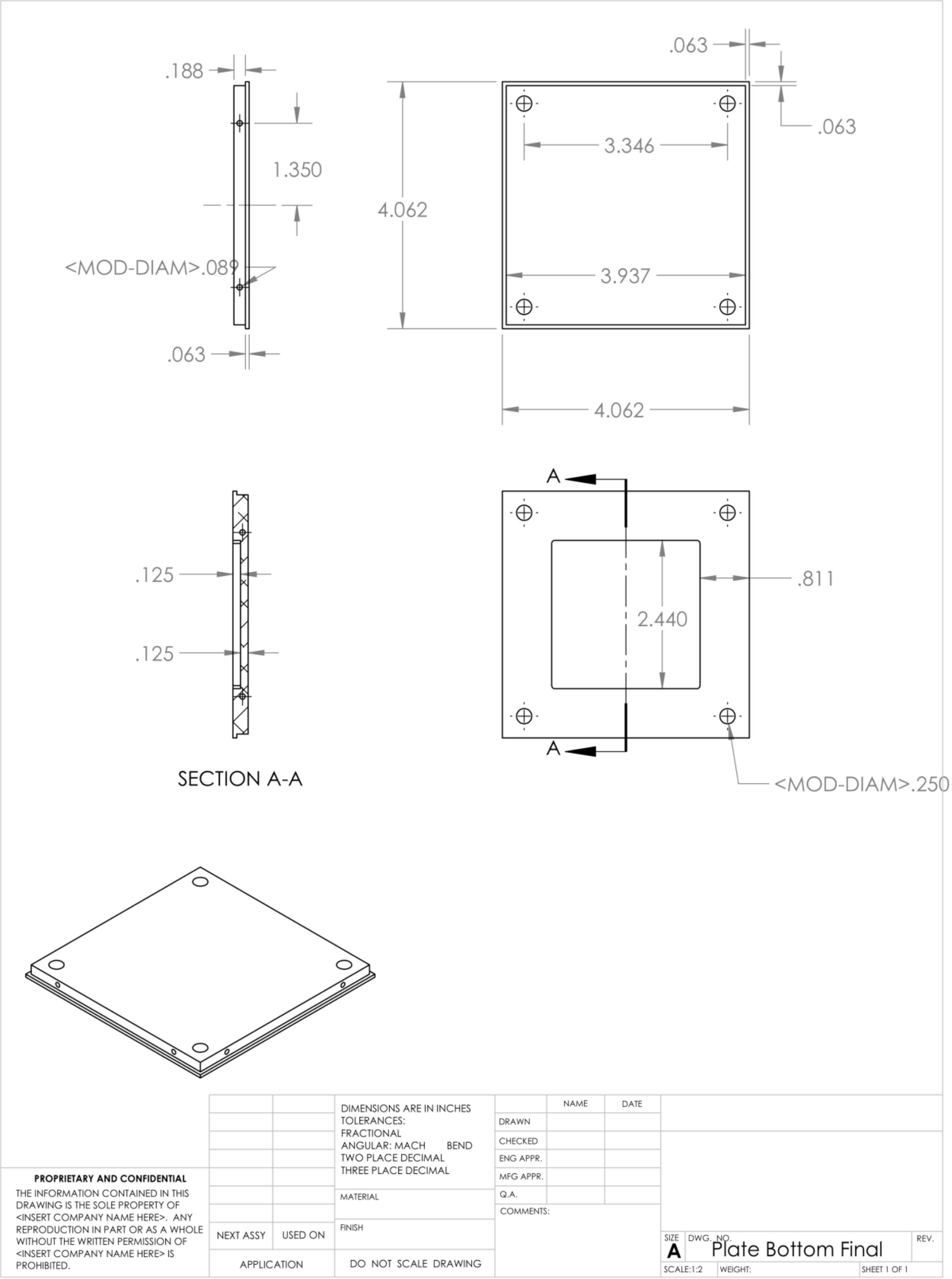

Figure 13. Mechanical drawing of bottom plate of 2.5-U and 3-U HAXDT structure with dimensions in inches.

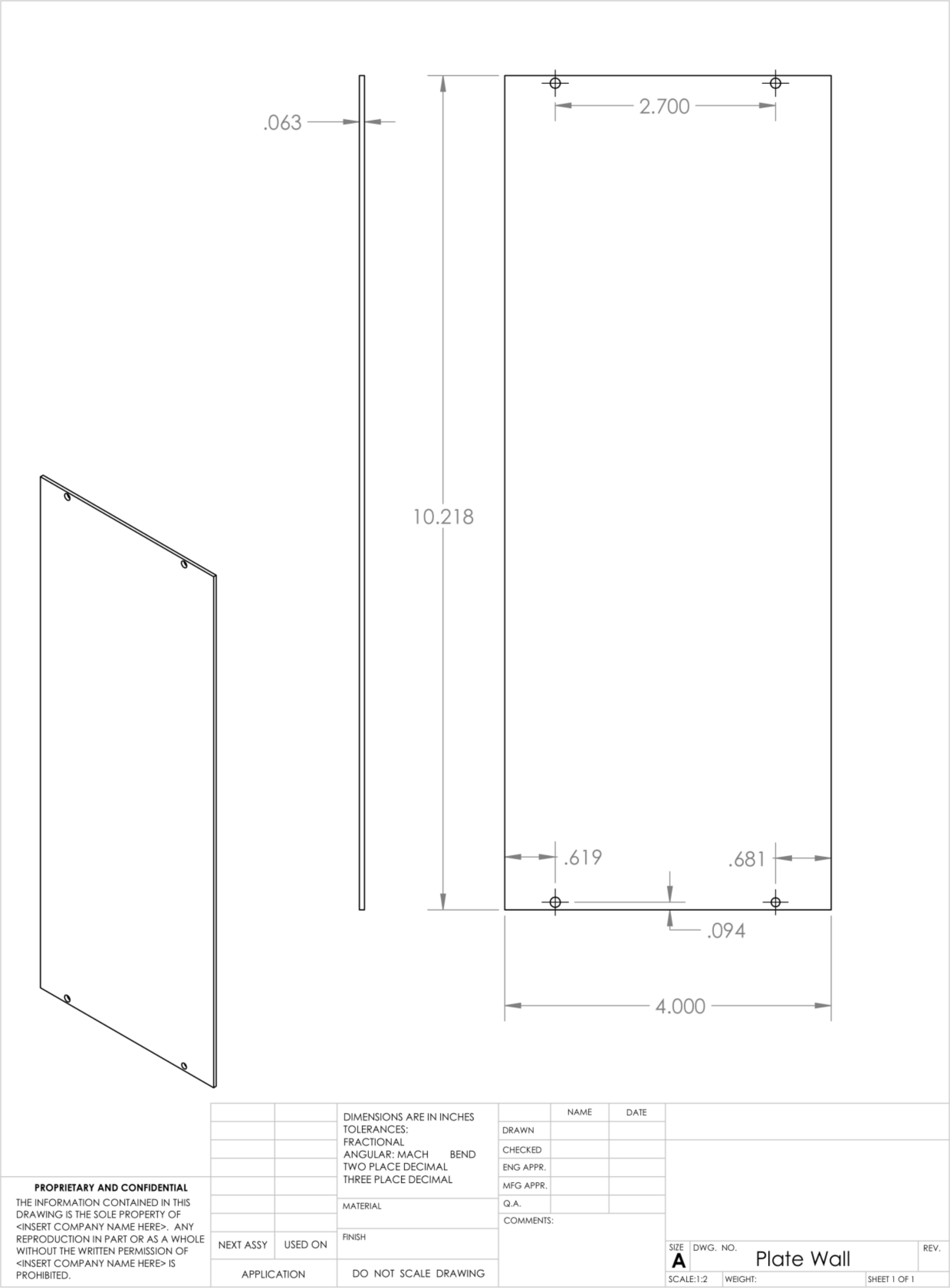

Figure 14. Mechanical drawing of 2.5-U HAXDT structure enclosing wall with dimensions in inches.

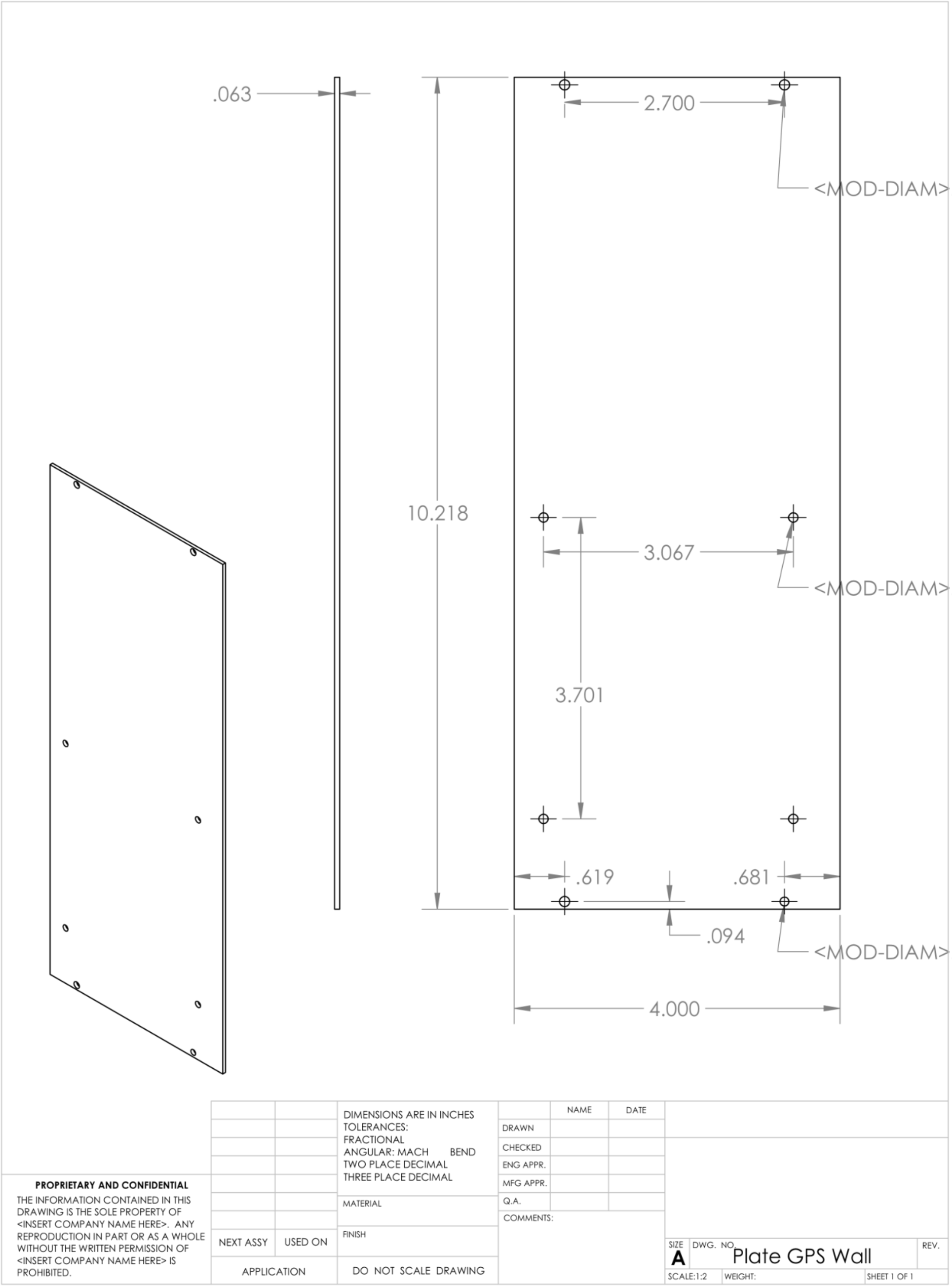

Figure 15. Mechanical drawing of 2.5-U HAXDT GPS mounting wall with dimensions in inches.

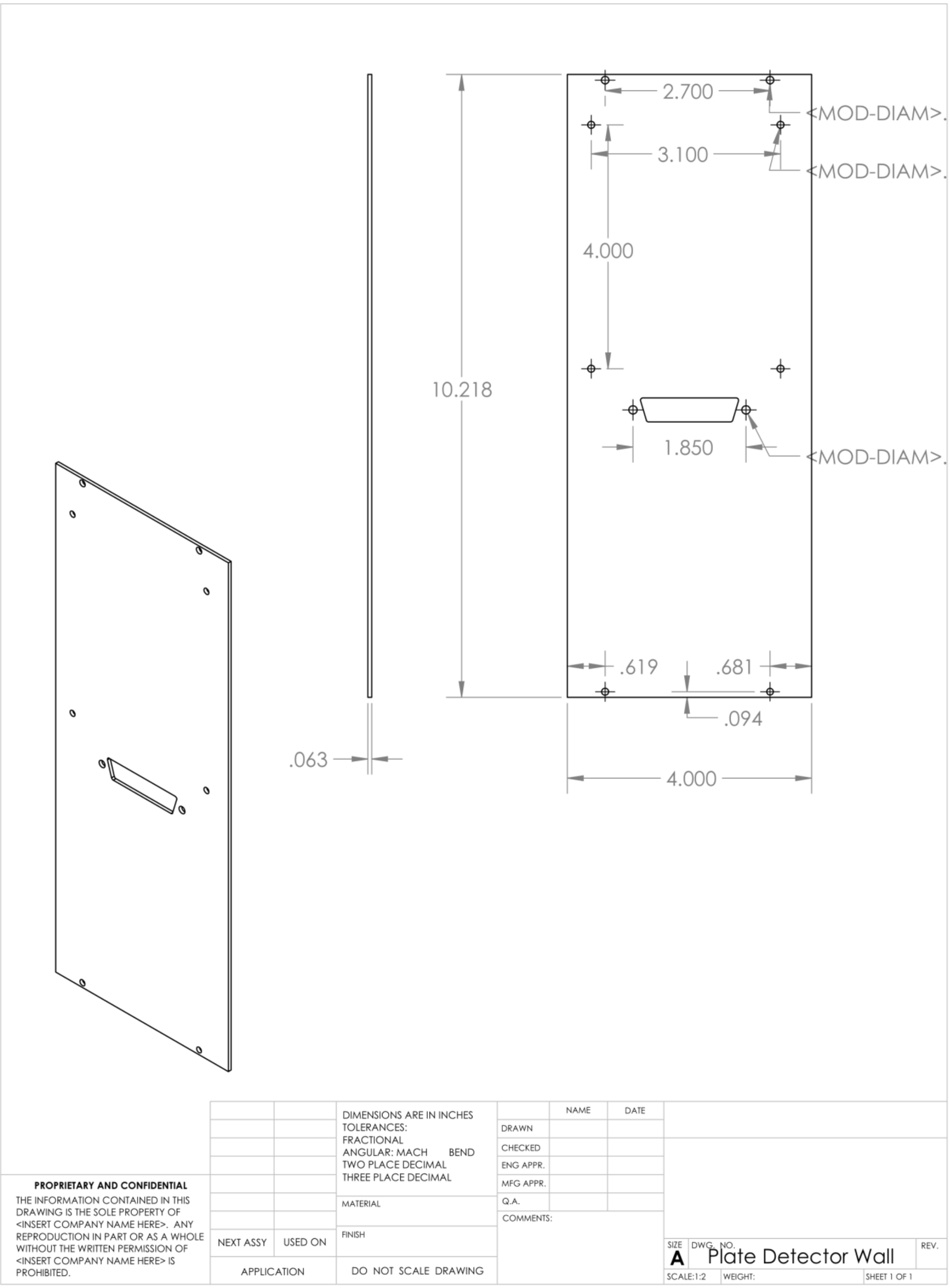

Figure 16. Mechanical drawing of 2.5-U HAXDT detector board mounting wall with dimensions in inches. The hole depicted is for a DB-25 connector for the HASP power, serial, and analog lines.

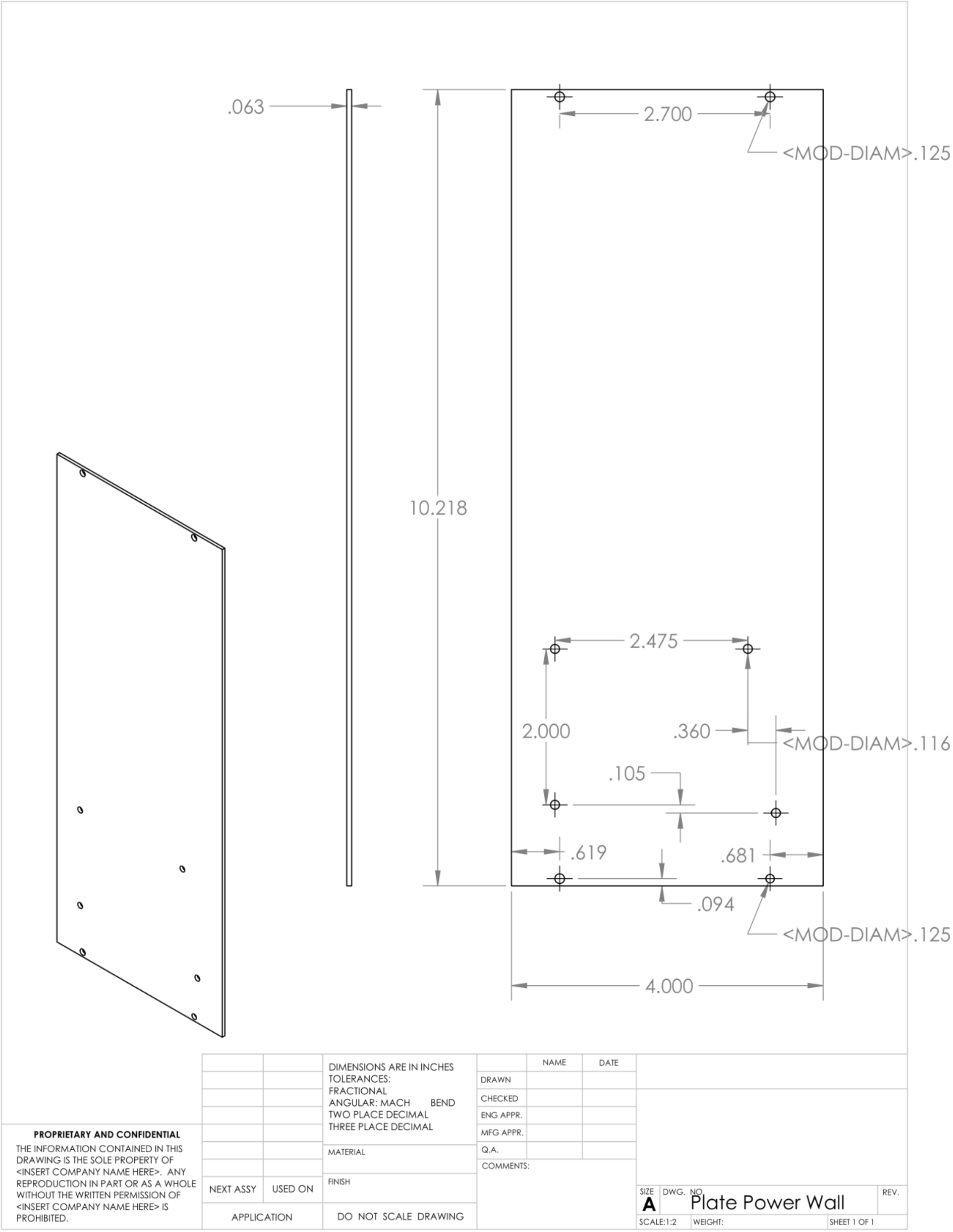

Figure 17. Mechanical drawing of 2.5-U HAXDT flight computer/IMU/power circuit bundle mounting wall with dimensions in inches.

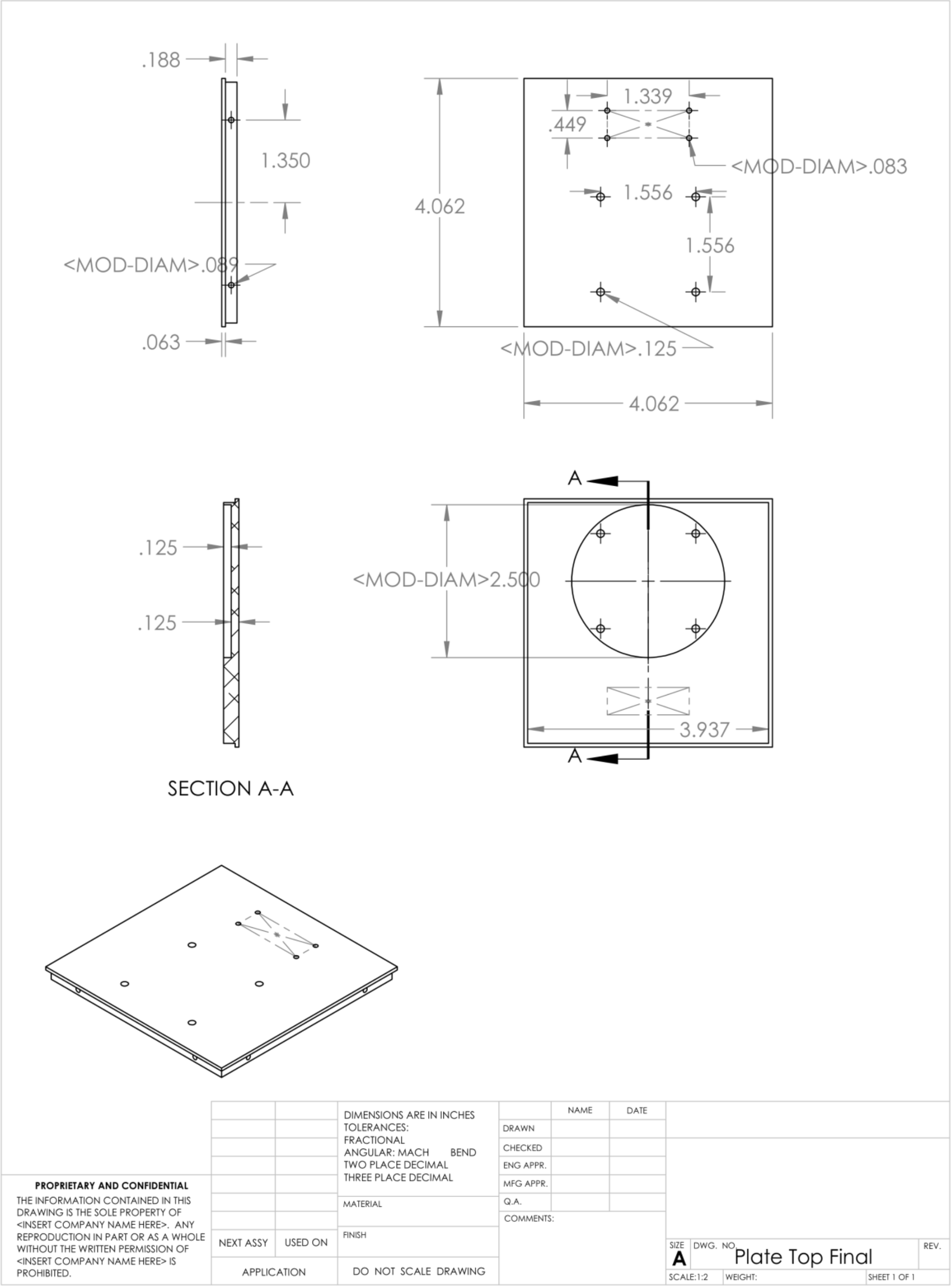

Figure 18. Mechanical drawing of top plate of 2.5-U HAXDT structure with dimensions in inches. This plate will be altered to accommodate two detector assemblies.

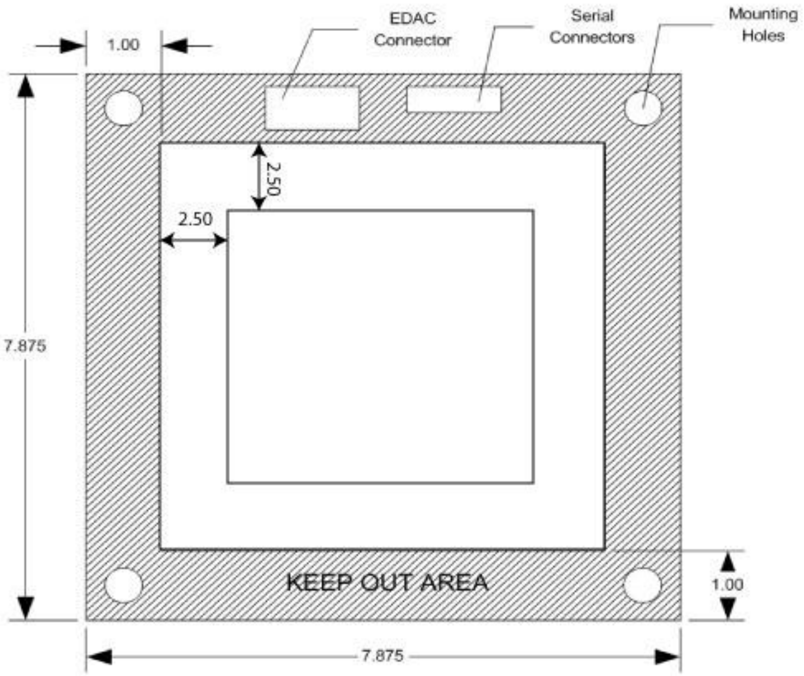

Figure 19. Anticipated 3-U HAXDT footprint on the HASP mounting plate. Note that the dimensions of the footprint are 2.50 cm (not inches) from the Keep Out Area.

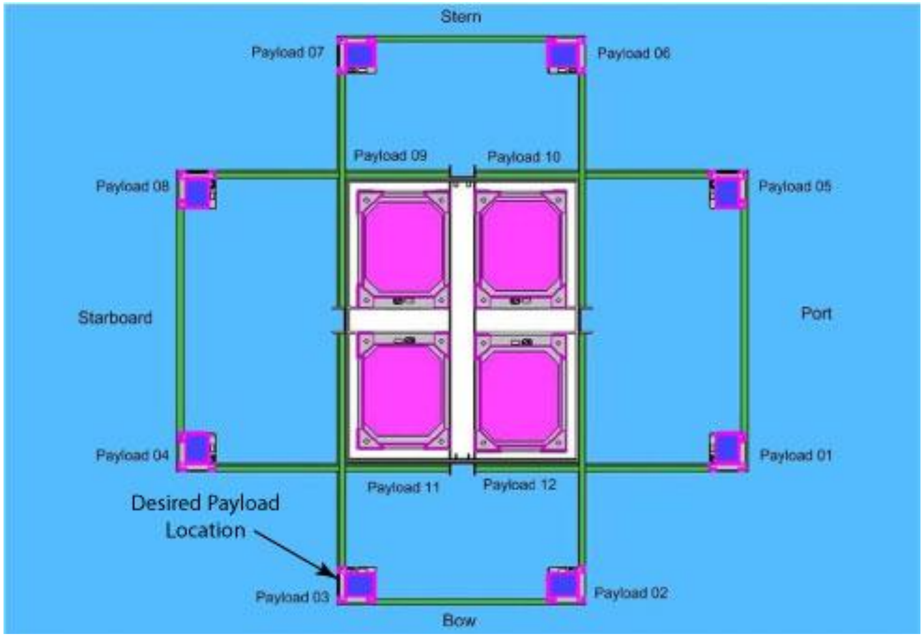

Figure 20. Desired payload location on the HASP gondola. Payload orientation does not depend on payload location.

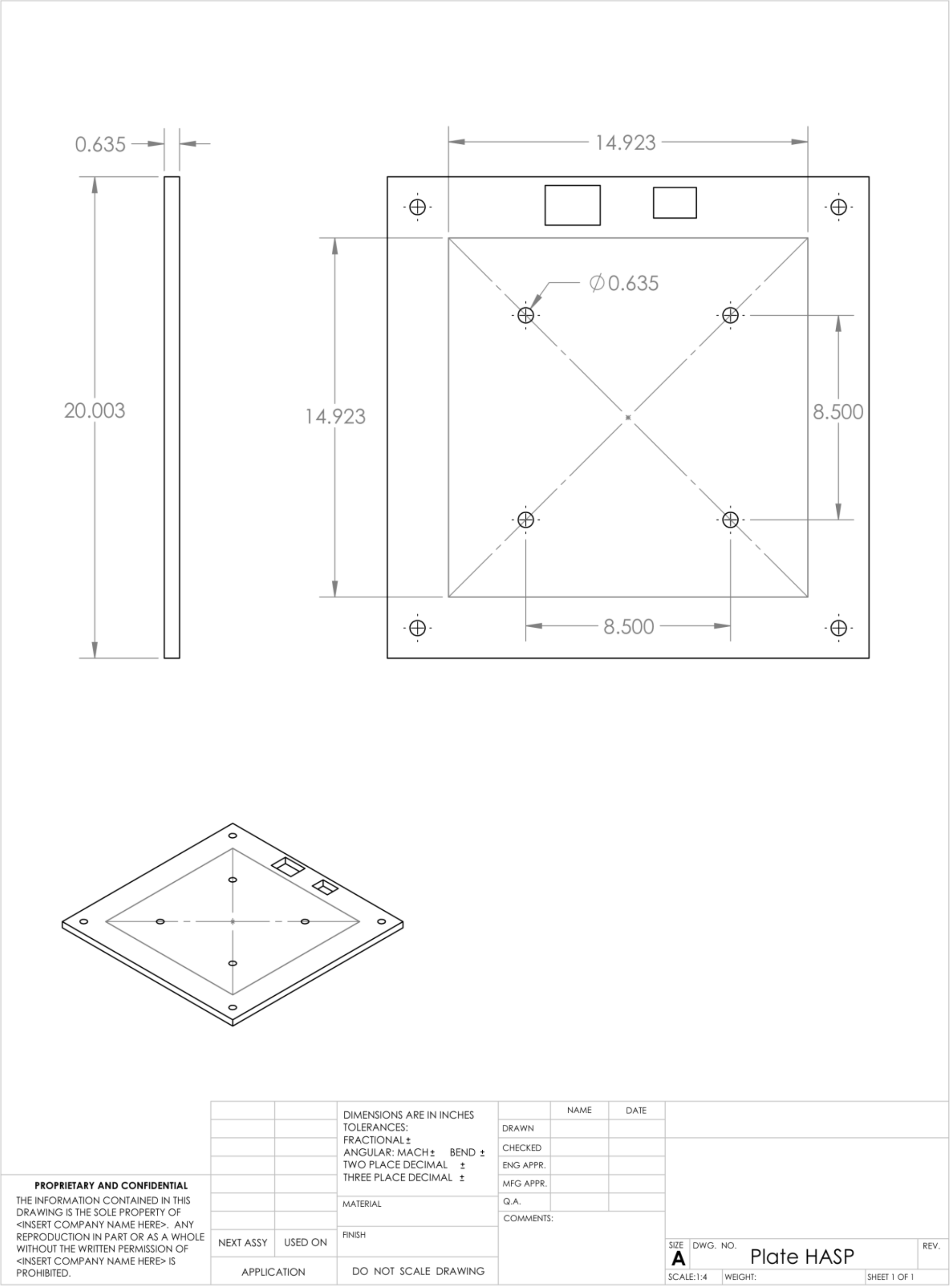

Figure 21. Anticipated modifications to the HASP mounting plate with dimensions in centimeters. Additionally, a hole will be drilled in the payload plate for the downward-looking camera.

References

1. “Next Generation Communications.” NASA Goddard Space Flight Center tech sheets, http://gsfctechnology.gsfc.nasa.gov/TechSheets/XRAY_Goddard_Final.pdf
2. Ray, Paul S., et al, “Deep Space Navigation Using Celestial X-ray Sources.” ION NTM, 2008, San Diego, CA.
3. Sheikh, Suneel I., et al, “Relative Navigation of Spacecraft Utilizing Bright, Aperiodic Celestial Sources.” ION 63rd Annual Meeting, 2007, Cambridge, MA.
4. Sheikh, Suneel I., et al, “Spacecraft Navigation Using X-ray Pulsars.” *Journal of Guidance, Control, and Dynamics*, Vol 29, No 1, 2006.
5. Sheikh, Suneel, I., et al, “Absolute and Relative Position Determination Using Variable Celestial X-ray Sources.” 30th Annual AAS Guidance and Control Conference, 2007, Breckenridge, CO.
6. Graven, Paul, et al, “XNAV Beyond the Moon.” ION 63rd Annual Meeting, 2007, Cambridge, MA.
7. Sheikh, Suneel I., “The Use of Variable Celestial X-ray Sources for Spacecraft Navigation.” Department of Aerospace Engineering, University of Maryland, Ph.D. thesis, 2005.
8. Woodfork, D. W. “The Use of X-ray Pulsars for Aiding GPS Satellite Orbit Determination.” Department of Electrical and Computer Engineering, Air Force Institute of Technology, Master of Science thesis in Astronautical Engineering, 2005.
9. Hanson, John, et. al, “Noise Analysis for X-ray Navigation Systems.” IEEE-ION PLANS, May 2008.
10. Peterson, L.E., et. al, “Techniques in Balloon X-ray Astronomy.” Space Science Reviews, 13:320-336, 1972.