West Virginia University

HASP Student Payload Application for 2008

Payload Title: Distant Aerial Cosmic Radiation Acquisition Package

Payload Class: (circle one) [✓ Small] ~~Large~~	Institution: West Virginia University	Submit Date: 12/17/07

Project Abstract:

Cosmic radiation is one of the main factors standing against space exploration and high altitude activities, due to its hazardous effects on both humans and instrumentation. A better understanding of cosmic radiation, by studying the intensity of radiation at different altitudes, can help to pave the road to a wide range of applications.

The proposed experiment will measure the intensity of cosmic radiation with respect to altitude and time, and classify different types of radiation according to their energies. An initial form of this experiment was previously conducted, on Labor Day 2007, by another team from West Virginia University, through the HASP program. To achieve a more reliable scientific outcome, it was decided to take this experiment to the next level, and modify the design by changing the instrumentation to obtain a wider range of measurements. This team will also eliminate the failure elements, one of which caused the last year's apparatus to stop working at night. It is important to note that the rate of solar particles is at its minimum during sundown, a very important time frame for studying the radiation coming from outside the solar system.

This team is comprised of two faculty members and two students from the West Virginia University Mechanical and Aerospace Department and one student from WVU Physics Department.

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1 Theory and Background

1.1 Theory

Cosmic rays are high-ionizing, high energy particles (also known as HZE particles) that come from outer space. The composition of cosmic rays includes the nuclei of atoms and energetic particles such as positrons, high energy electrons, neutrinos, and other high energy particles. Energetic particles from the sun also fall into the category of cosmic rays. Cosmic rays are normally measured in units of MeV or GeV. One eV is the energy of an electron that is accelerated through a potential difference of 1 volt. Galactic cosmic rays have energies between 100 MeV (corresponding to a velocity for protons of 43% of the speed of light, where the speed of light is $3\text{x}10^8$ m/s), and 10 GeV (corresponding to a velocity of 99.6% of the speed of light) [1]. The source of Galactic cosmic rays is believed to be supernova explosions, which occur around once every 50 years in the Milky Way Galaxy. The composition of cosmic rays is estimated to be about 89% protons (Hydrogen nuclei), 10% alpha particles (Helium nuclei), and 1% heavier elements [1]. Cosmic rays are separated into two categories, primary and secondary. Cosmic rays that reach Earth's atmosphere are termed primary cosmic rays. These primary particles collide with other particles in the upper atmosphere, at very high speeds, to produce a shower of subatomic particles known as secondary cosmic rays. These secondary cosmic rays have a much lower energy than the primary radiation and include pions, muons, neutrinos, and gamma rays. The number of cosmic rays that reach the Earth's surface is related to the energy of the particle that struck the upper atmosphere. Most of the cosmic rays that reach the Earth's surface are muons with an intensity of about 100 counts per m^2 per second [1]. Although this is a relatively large intensity, the resulting radiation levels are harmless. However, this intensity grows with altitude and can be harmful to pilots and astronauts. These high energy particles can also cause damage to electronic devices at high altitudes and in space. Just as these cosmic rays are deflected by the magnetic fields in interstellar space, they are also deflected by the magnetic field inherent in solar winds. For this reason, during periods of high solar activity, galactic cosmic rays have trouble reaching the inner Solar System. The sun is also a source of cosmic rays that varies along its eleven year solar cycle. For instance, during times of solar flares or coronal mass ejections the intensity of energetic particles can increase by a factor of 10^2 to 10^6

[1]. Due to this fact, the team is interested in collecting data when the sun goes down, in order to obtain more accurate readings of galactic cosmic rays.

1.2 Background

Cosmic rays were first discovered by Victor Hess in 1912, when he noticed that an electroscope discharged more rapidly as he ascended in a balloon [1]. In 1936, he was awarded the Nobel Prize for his discovery. It was first believed that cosmic rays were part of the electromagnetic spectrum. It has since been deduced that they must be electrically charged because they are affected by magnetic fields. Before man-made particle accelerators were developed that could reach the GeV range, cosmic rays were a source for High Energy Physics. Initially, cosmic ray research led to the discovery of the positron, among other high energy particles. Now, current research is focused more on the astrophysical questions of where they originate, how they are accelerated to such high velocities, and what their composition tells scientists about the galaxy. The best way to measure these cosmic rays is with detectors on spacecraft or with high altitude balloons. West Virginia University's 2006-2007 HASP project sought to measure the intensity of cosmic rays versus altitude and time. The resulting data was analyzed and efforts were made to relate it to the cancer rate in pilots. This year, the West Virginia University High Altitude Research Team's Distant Aerial Cosmic Radiation Acquisition Package has much more ambitious goals. The team hopes to build on the astrophysical research of others; thus the students will focus their research and data analysis on the physics of cosmic rays. More specifically, the researchers will focus on classifying the energy and intensity levels at various altitudes and points in time.

2 Payload

2.1 Experiment Description

The measurement of cosmic radiation remains as a significant issue, especially in the High Energy Physics community, yet is seldom investigated in real world environments, outside of particle accelerators. Therefore, the need for cost-effective experimentation is most abundant for further, more frequent, investigation of cosmic radiation. One such method for cost-effective experimentation is through Louisiana State University's High Altitude Student Platform (HASP).

LSU’s HASP allows for 8 small payloads and 4 large payloads to be attached to a central data acquisition system, all of which is suspended below a zero pressure balloon. The balloon, which is launched from Columbia Scientific Balloon Facility (CSBF) through the NASA Balloon Program Office, allows the payloads to ascend to an altitude of 36 km (22.4 mi), just below the Ozone layer in the Stratosphere, for a duration of 15 to 20 hours, allowing for thorough experimentation at altitude. To perform cosmic radiation testing at this altitude, the Distant Aerial Cosmic Radiation Acquisition Package has been developed.

Firstly, contained within this payload are a pair of scintillation blocks. The solid scintillation material is a solid rectangular prism of crystalline NaI(TI) structure. As a cosmic particle passes through the scintillation material, it loses energy and ionizes electrons within the material. As the electrons strive to settle back to their original states, energy is emitted in the form of visible light that is dependent upon the characteristics of the scintillation material. This flash of light climaxes to peak intensity within 1 nanosecond (ns), and is emitted over a duration of between 1 ns to 1 microsecond (μs) [2]. In addition, these scintillation blocks are oriented a distance apart along the gravity gradient, in other words, radially oriented from the Earth’s surface, for no other reason than to have a consistent orientation throughout the duration of the flight. Hence, when a particle creates a flash of light in both blocks of scintillation material within a specified time interval, known here as “coincidence,” it is approximated that a solid angle represents the local direction of the particle’s possible path. Since there are two blocks, this solid angle represents a certain percentage of a sphere’s volume. This angle is shaped as a square pyramid, with the tip chopped off (representing the block of scintillation material), however, the wider base of the pyramid is round, as it intersects the edge of the sphere. The same is true for both blocks of scintillation material, thereby representing only a certain percentage of the overall spherical area that is possible for particles to pass through. Additionally, this solid angle depends upon the distance between the two scintillation blocks. The farther apart the blocks, the narrower the angle, and the inverse is true as the scintillation blocks near one another. Thus, the farther apart the blocks, the more accurate the local path approximation, however, the number of particle counts that will be encountered will decrease. Therefore, there is a trade-off between separation distance and the number of particles that are measured.

Furthermore, to record the flashes of light, photomultipliers are perpendicularly connected to the broad surface of the scintillation material, as the scintillation material is not a cube, but rather a rectangular prism. As the incoming particle interacts with the scintillation material and emits luminescence, the light that travels nearly at the speed of light based on the scintillation material characteristics, which is then detected by the photomultipliers. When the light reaches the photomultiplier, it first hits the photocathode, the "lens" of the photomultiplier. The photocathode then turns the visible light into a comparable amount of photoelectrons. These photoelectrons then continue to hit a series of dynodes, each of which multiplies the number of photoelectrons, creating a chain reaction-like effect. The amplified number of electrons finally reaches the anode of the photomultiplier, where an electrical signal is produced, in the form of a voltage pulse. Two diagrams of a photomultiplier may be observed in Figures 1 and 2. This voltage pulse then passes through the circuitry to a comparator, which creates a pulse width of specified amplitude and length. This pulse width then passes to an electrical "AND" gate. If both comparators create pulse widths that are mostly overlapping during the specified time interval, the "AND" gate returns a digital 1, indicating coincidence in both scintillation materials. If coincidence occurs, the particle is assumed to have come from a direction within the altered square pyramidal volume, described previously as the limits of the solid angle.

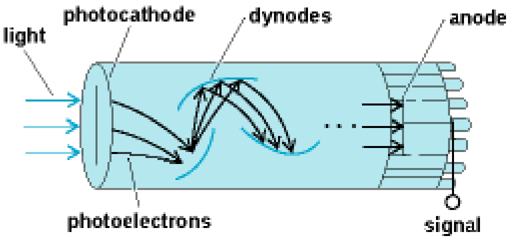

Figure 1: Sequential Schematic of a Generic Phtomultiplier [3]

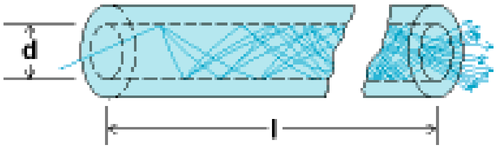

Figure 2: Amplification Schematic of a Generic Photomultiplier [3]

2.2 Payload Specifications

This project will be designed to meet all of the HASP small payload requirements. The platform for this year's project will build upon last year's model, making several modifications. Based on the 2007 model, it is believed that the project will weigh approximately 800 g to 1 kg. However, it is unclear as to whether the maximum weight for the 2008 small payload is 1 kg or 3 kg. Depending on the weight limit, modifications will be discussed in the Section 3 (*Justification and Modifications for Reflight*). The payload will also meet the maximum footprint specifications of 15 cm x 15 cm. It may be necessary as construction begins that the payload box include an overhang on two sides beginning approximately 5 cm above the mounting plate, as allowed in the HASP-Student Payload Interface Manual. The payload will be designed to be shorter than the 30 cm maximum height limitation. Epoxy and bracketing assembly will be used to attach the project to the mounting plate. The payload will also be mounted such that it is compressively restrained to the mounting plate. The material used for the bracketing will most likely be aluminum. The payload will adhere to the allotted 28 V DC limit and 0.5 A current limitations, supplied from the HASP bus, to power the photomultipliers, onboard electronics, and a thermal management system. Each of these subsystems will require different input voltages. Therefore, the supplied voltage will be run through voltage switchers, which will be integrated in the payload electronics stack. One of the main power consumers in the payload will be the photomultipliers, each of which require a 1000V input. This voltage can be achieved using a switching power supply. All payload operations will be managed by a CPU, embedded with executable commands. An onboard GPS unit will be used for tracking. This will allow for the data recovered from the electrical circuit to be associated with the altitude and position of the coincident strike. The payload will use the standard DB9 and EDAC 516 connectors to interface with the HASP. Based on last year's project, data will be transmitted to the HASP for downlink every 10 seconds. This will allow the team to confirm the proper operation of the payload throughout the flight. This transmitted data will include a GPS time stamp, payload temperature, and photomultiplier counts, using a checksum or CRC format and a package size of 1400 bytes. This allows multiple readings to be packed together. The inside temperature of the payload will be managed by the use of Minco Thermofoil^{TM} heaters. These heaters will be controlled using an onboard routine that will switch them on and off, according to the internal temperature measured by a thermistor. These heaters will not significantly add to the payload weight. The payload will also stay under the 0.5 Amp current limit. The construction and preparation of the Distant Aerial Cosmic Radiation Acquisition Package will be completed prior to integration in July 2008. During this time, the team plans to attach the payload, verify proper communication and supplied power, and also test the package at low temperature and pressure in an environmental chamber.

3 Justification and Modifications for Reflight

Even though last year's project yielded useful results, it encountered problems that caused some apparatus failures, the most important of which occurred during flight. No data was collected after sunset, consequently eliminating the data needed to study cosmic radiation while the Earth blocked the sun's rays. This period of the project was of key importance, because the amount of solar particles is at its minimum at night, which allows for the accurate measurement of radiation that comes from sources other than the sun. As of now, there are no definitive answers as to why this problem happened. It has been conjectured that this problem was caused by a malfunction of the potting associated with the photomultipliers. A primary goal of this year's team is to find the cause of this failure and correct it in preliminary testing. However, to do so with certainty, the team will need to test the apparatus in a simultaneously-controlled low-pressure-low-temperature environmental chamber, prior to or during the payload integration process in Palestine, TX.

Another failure, which occurred prior to flight, was that the apparatus had a high voltage startup transient, and consequently blew the HASP's startup fuse. This problem was fixed prior to the launch with some last-minute adjustments. However, to avoid encountering the same problem this year, the current team will design the circuit to include a Field-Effect Transistor (FET), which gradually increases the startup voltage and limits the current transient.

There were also some problems with the data acquisition, where random bits of information were generated, which had no physical meanings. These random bits were later believed to possibly be glitches in the software, which are easily modified to account for the problem. However, it is also possible that these random bits were caused by Single-Event Upsets (SEUs). As stated by NASA scientists, SEUs are defined as:

> "… a change of state or transient induced by an energetic particle such as a cosmic ray or proton in a device. This may occur in digital, analog, and optical components or may have effects in surrounding interface circuitry (a subset known as Single Event Transients (SETs)). These are 'soft' errors in that a reset or rewriting of the device causes normal device behavior thereafter" [4].

To alleviate this problem, the team plans to shield the circuitry in Polyethylene, a material which has a dense Hydrogen structure, acting as an efficient deterrent to cosmic radiation. If not restricted by the 1 kg weight limit, Lead (Pb) is considered as another possible shielding material. Placing the shielded circuitry near the bottom will also block the secondary cosmic "spray" from particles interacting with the exterior aluminum frame. Last year, another problem arose when there was a miscommunication, which led to the decision to change the data format from ASCII to Transistor-Transistor Logic (TTL). Later, however, it was discovered that the original ASCII format was correct. This year, the miscommunication will be avoided and the data will be formatted properly. Overall, these problems will be fixed by redesigning the circuitry and using more reliable measurement devices.

In addition to these modifications, the team plans to add a temperature and pressure sensor to the package. These two instruments will allow the team to obtain atmospheric data for that specific date, to more accurately model the atmospheric conditions rather than relying on the standard atmospheric model.

4 Possible Advanced Modifications

Based upon several varying factors, the WVU HART believes that possible advanced modifications could be designed to study cosmic radiation more in depth. The possibility of these modifications depends heavily on the accuracy of the instrumentation available, the circuitry associated with the instrumentation, and the available funding.

Firstly, if the advanced circuitry that is to be designed, and the weight restrictions permit, the team is currently working on a new configuration for detecting cosmic particles. This configuration will allow for the coordinate detection of incoming cosmic particles, in three-dimensional space, within the scintillation material. Thus, this configuration could lead to the approximate determination of the cosmic particle's localized, linear path. This updated design contrasts with current measurement methods, which contain a pair of scintillation blocks a certain distance apart, that can only measure coincidence and approximate the path based on an arbitrarily desired solid angle, contained within the altered square pyramidal volume.

Secondly, it is planned that the reduced data will primarily focus on the classification of cosmic particles based on their varying energies, which can then be applied to current research focused on the interaction between human biology and cosmic radiation, as well as electrical circuitry interference. The classification of cosmic particles may be performed by simple measurements based on the electrical output of the photomultipliers, in the current configuration. The electrical voltage reported by the photomultipliers is proportional to the time interval over which the light is emitted within the scintillation material. Additionally, the square wave pulse that is produced by the comparators is of specified amplitude, as to include the lowest voltage output by the photomultiplier according to particle luminescence, yet eliminating electrical noise output during periods when no particle counts are being recorded. Thus, when the voltage output crosses the comparator square wave pulse, the time that the photomultiplier output remains below the square wave amplitude can determine relative classifications of particles based on the energy level, which is proportional to the duration of time that light is emitted within the scintillation material. Furthermore, it may be possible to determine the speed of incoming particles. The scintillation blocks are separated by a specified distance. When an incoming particle's path is such that it lies within the altered square pyramidal volume, coincidence is bound to occur, and thus an output from both photomultipliers will produce two square waves, one from each comparator. However, these two square waves will not perfectly overlap one another, but be offset by some time interval. This offset time interval represents the delay between the detection of light within each scintillation block by its representative photomultiplier. Thus, the time the particle takes to travel between two scintillation blocks, and the distance between the blocks is known, thereby allowing for the calculation of the speed of that particle. It is hoped that this data will at least be able to confirm the order of magnitude of the particle velocity. The accuracy of this calculation will be limited, however, by the speed at which the photomultipliers can respond to the flashes of light, and how fast the circuitry can produce pulses accurately.

5 Project Management

5.1 Team Structure

The West Virginia University's High Altitude Research Team consists of two faculty members Dr. Mike Palmer and Dr. John Kuhlman, as advisors, from the West Virginia University Mechanical and Aerospace (MAE) Department, two dual major MAE students, Kyle Phillips and Mehran Mohebbi, and one Physics student, Justin Ellis. The team leader and point of contact is Mehran Mohebbi. The tasks are evenly distributed between the team members and the progress is reported to the advisors during weekly meetings. The project timeline can be seen in Table 1. All team members and advisors will attend the payload integration at Columbia Scientific Balloon Facility (CSBF), in June 2008, and the launch from Ft. Sumner, NM in September.

As of now, team has a verbal commitment from NASA West Virginia Space Grant Consortium (WVSGC) and West Virginia University College of Engineering and Mineral Resources (WVU CEMR) to fund the anticipated equipment and travel expenses.

5.2 Project Timeline

Table 1: One-year Project Timeline

Team's Project Timeline		Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08	Oct-08	Nov-08	Dec-08
Pre-Proposal	Team Formation	🟩													
	Preliminary Research	🟩													
	Technical Research and Theoretical Developments		🟩												
	Proposal Submission		🟩												
Post-Proposal & Pre-Launch	Acceptance Notification			🟩											
	Purchasing Equipment				🟩	🟩									
	Constructing Apparatus				🟩	🟩	🟩								
	Testing and Analyzing Data							🟩	🟩						
	Final Testing, Construction, and Modification								🟩						
	Integrating with HASP Platform at CSBF								🟩						
	Preflight Testing and Modification										🟩	🟩			
	Launch at Ft. Sumner, NM											🟩			
Post-Launch	Data Reduction and Analysis											🟩	🟩	🟩	🟩
	Final Report Submission														🟩

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Appendix A[1]

Payload Schematic

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[1] The figures contained within Appendix A are taken from WVU’s previous HASP research team [6], as the same structural drawings are representative of this year’s WVU HART.

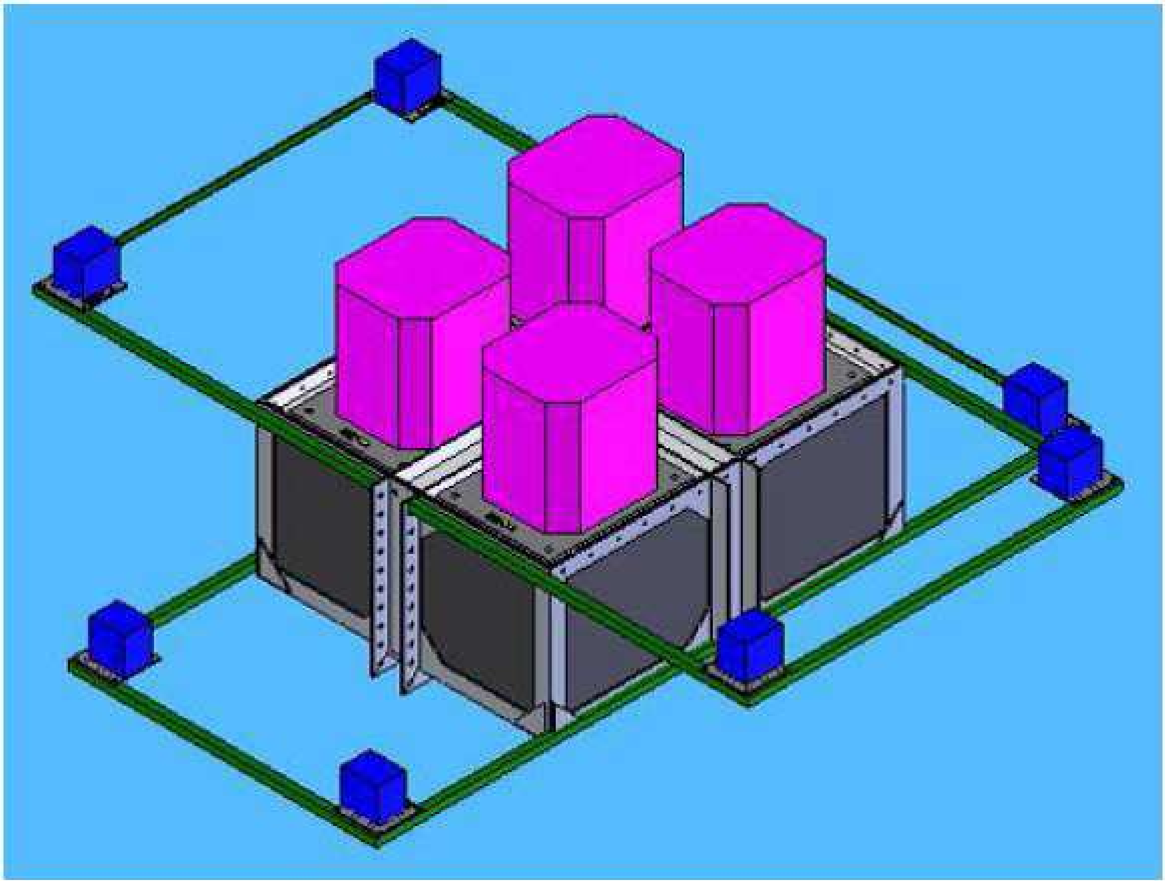
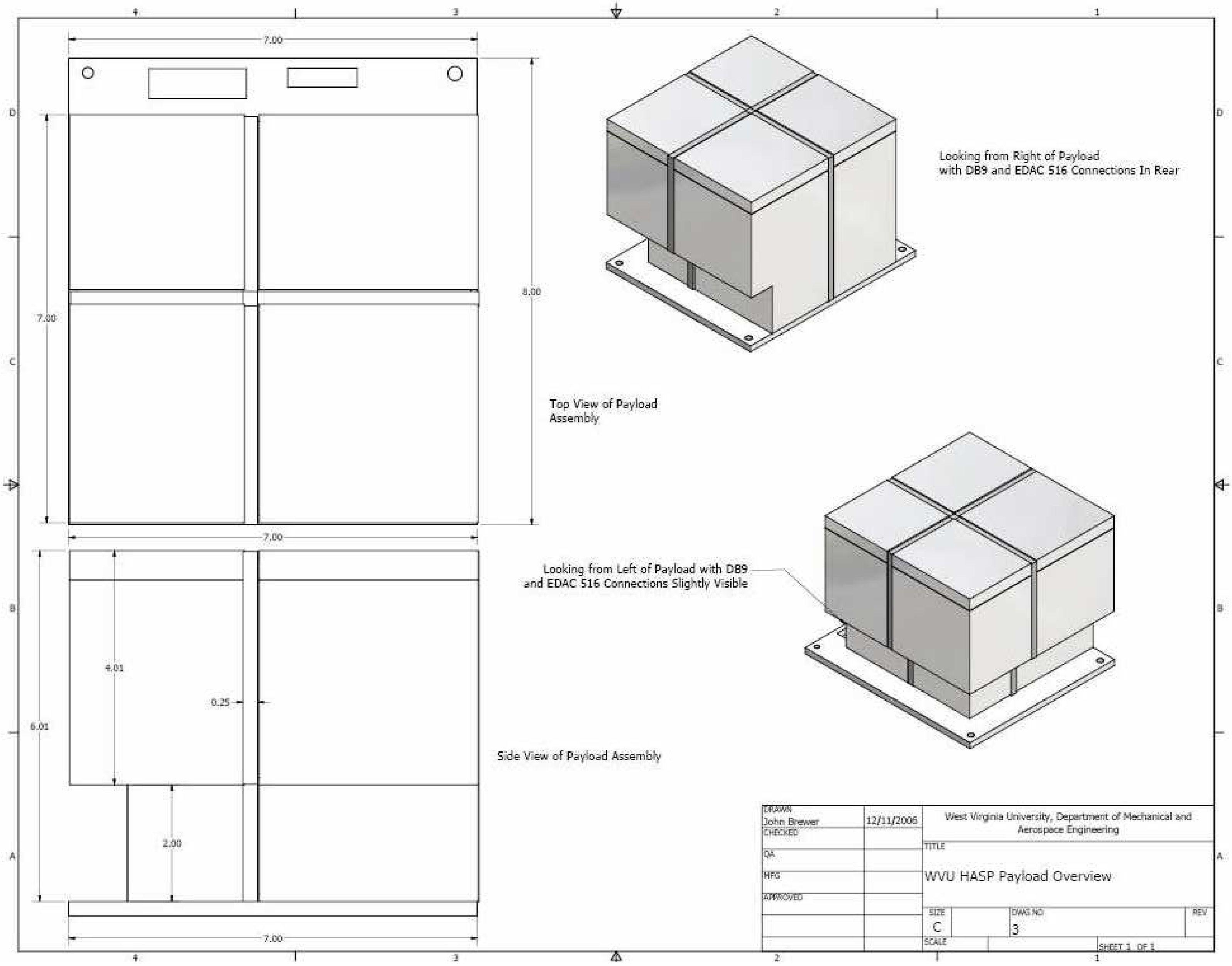


Figure A1: High Altitude Student Platform (HASP) General Configuration [5, 6]

Note: West Virginia University's High Altitude Research Team's payload will be specified as a "small payload," in accordance with HASP guidelines. In Figure A1, small payloads are represented by blue boxes. The orientation of WVU HART's payload must be oriented such that it lie vertically along the gravity gradient, for the purpose of maintaining a constant reference frame of known orientation.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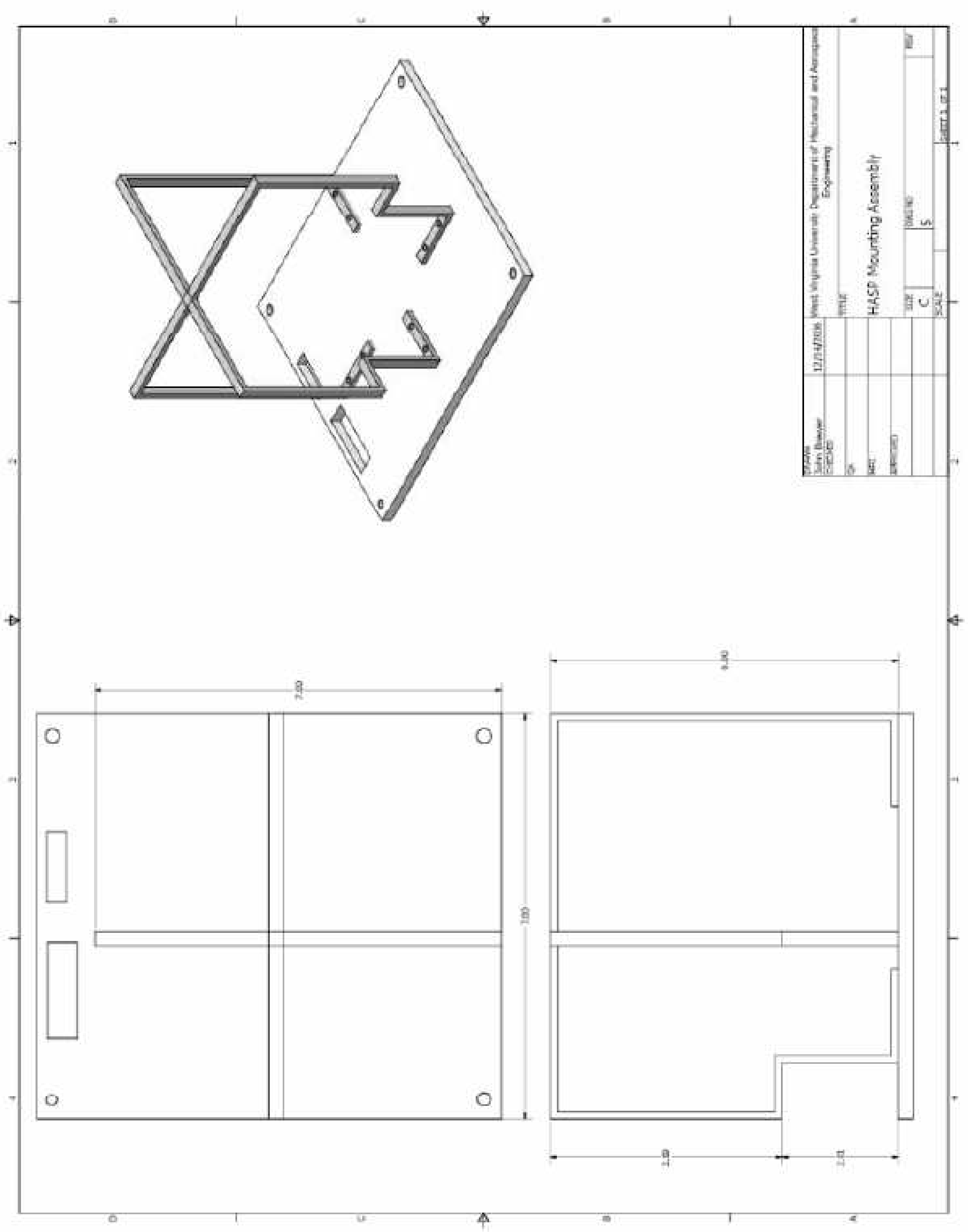
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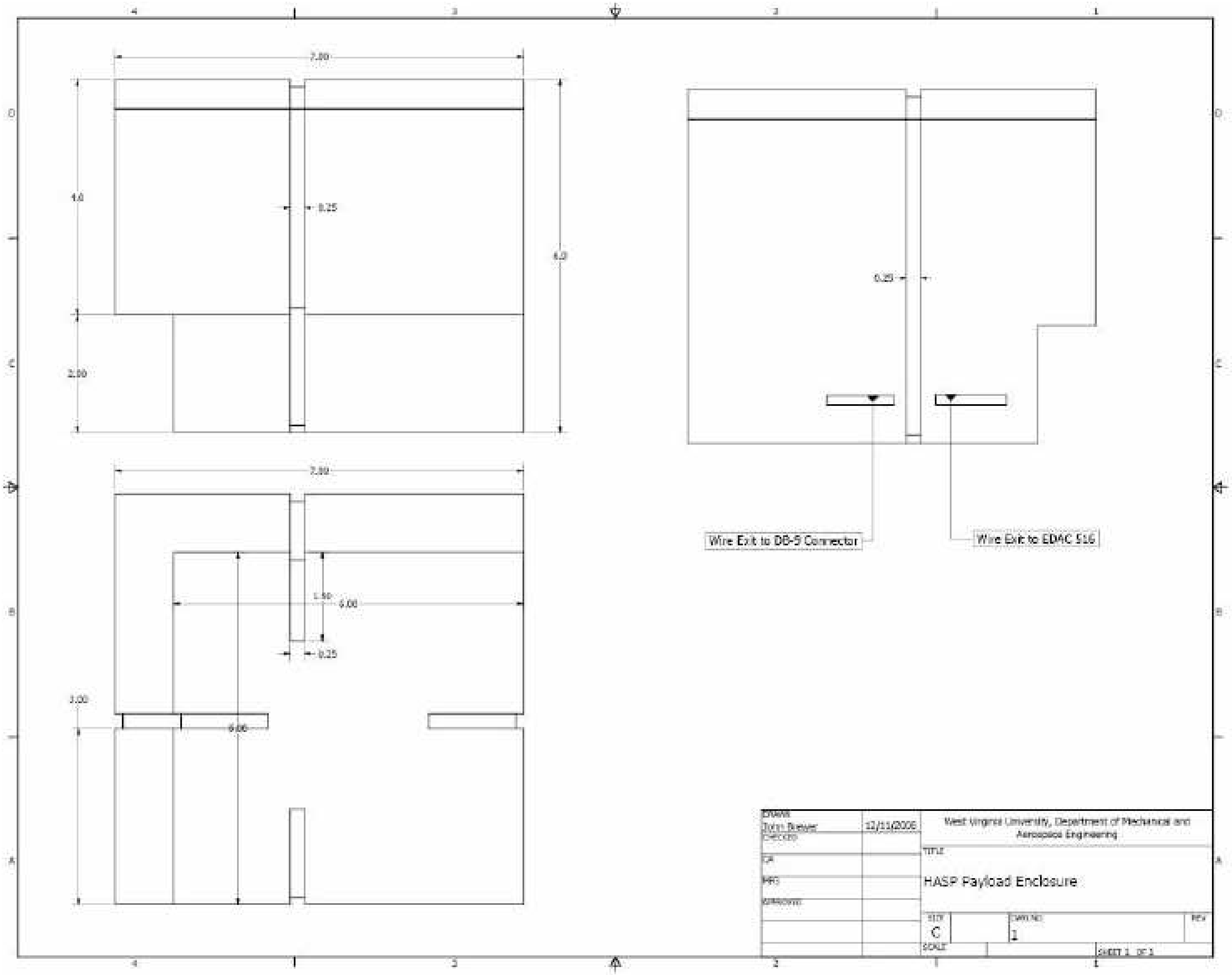
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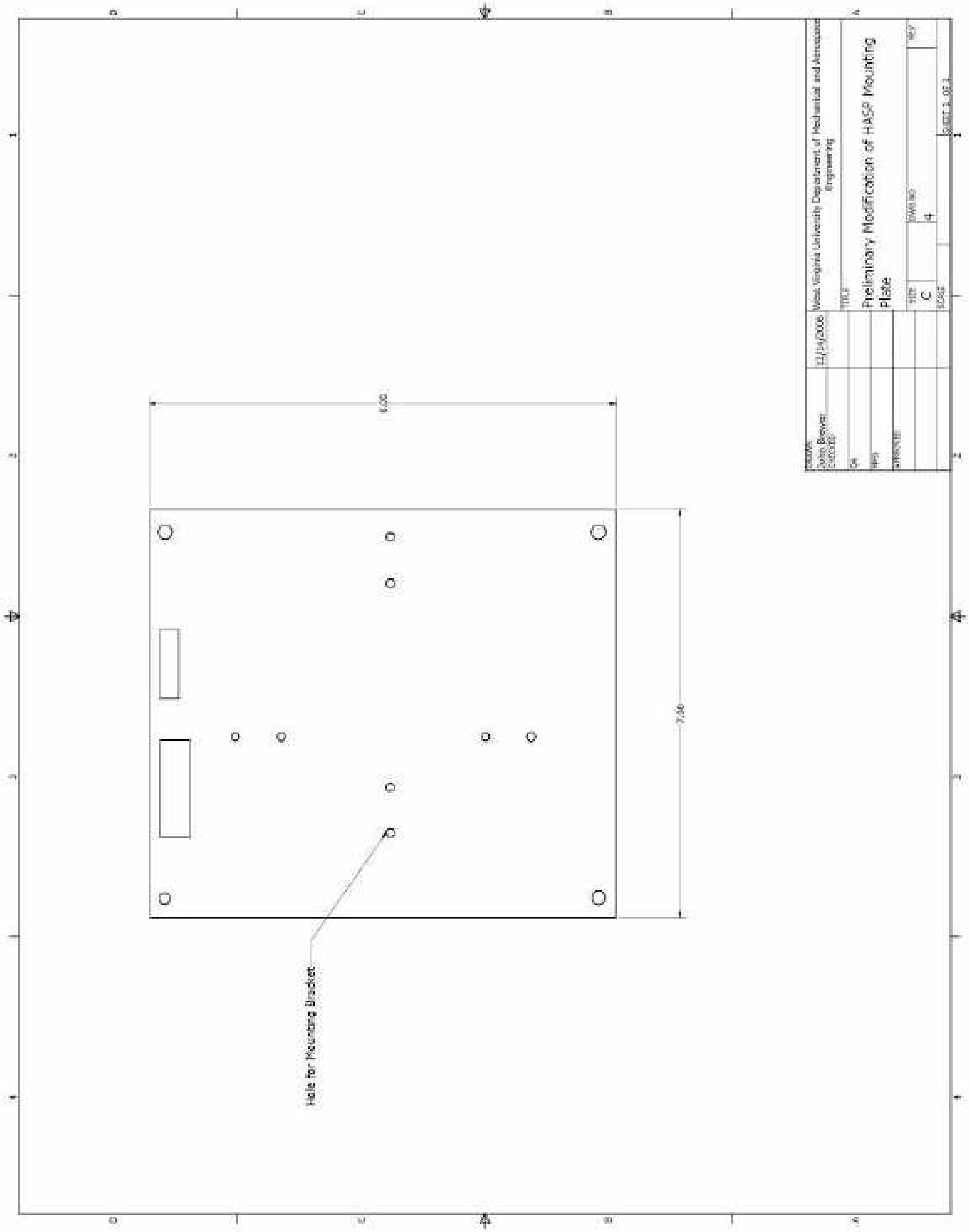
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