HASP Student Payload Application for 2019

Payload Title:
Stratospheric Measurements of Charged & Neutral Radiation – Part III

Institution: McMaster University

Payload Class (Enter SMALL, or LARGE): SMALL

Submit Date: December 14th, 2018

Project Abstract:
With recent greater interest in human space flight, there exists a need for health monitoring of astronauts. The hostile radiation environment of space poses a serious and complex risk to the health of astronauts during extra-planetary missions. Current estimates of consequential adverse health effects remain highly imprecise due to uncertainties in radiation quality factors. Recent estimates of cancer risk projections for a typical Mars mission have associated uncertainties of 400-600%. Existing space qualified radiation detectors lack the ability to accurately measure radiation quality factors. Specifically, the active monitoring of exposure to neutrons, a major radiation dose hazard, is inadequate. To address this challenge, we have developed the Charged & Neutral Particle Tissue Equivalent Proportional Counter (CNP-TEPC), a unique radiation dosimeter with the capability of separating radiation dose contributions from charged and neutral radiation. The tissue equivalence of the detection system enables the collection of meaningful data since the dosimeter behaves analogously to a human cell. This real time radiation measurement device satisfies all radiation monitoring requirements of manned missions to low Earth orbit and future manned missions into deep space. A balloon flight will allow for the characterization of the instrument in a near space environment and play a key role in our mission of classifying radiological hazards in space. With major mechanical, electrical, and software advancements made during the HASP 2017 and 2018 flight campaigns, a fully functioning CNP-TEPC instrument with the capability of transmitting spectral data will be developed.

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Stratospheric Measurements of Charged and Neutral Radiation – Part III

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1. Mission Overview

1.1 Executive Summary

As humanity prepares once again to venture beyond Earth's protective magnetosphere, to interplanetary destinations (e.g., Moon, Mars, and near-Earth asteroids) that hold incredible potential for scientific discovery, astronauts will risk receiving life threatening radiation doses from exposure to a hostile radiation environment that is more complex, intense, and variable than the one experienced on or near Earth. Cancer risk projections from such exposures are still highly uncertain [1–7] as they rely on estimates for the radiation quality factors and on biophysical models of relative biological effectiveness derived from radiobiological studies performed using terrestrial particle accelerator sources. Recent estimates by Cucinotta et al. [2, 8] showed the uncertainty in cancer risk projections for a typical Mars mission are approximately 400 – 600% and identified uncertainties in radiation quality factors as the dominant source of error.

While biological risk models are used to make the ultimate go/no-go decision, active radiation dosimeters with spectroscopic capabilities are necessary to measure radiation quality factors and characterize the radiation exposure to astronauts. Personal and area monitoring radiation dosimeters are required on every manned spaceflight in order to confirm compliance with regulations and indicate when dose rates become too high for a mission phase, such as extra-vehicular activities. Radiation dosimeters for manned spaceflight missions must be designed to (1) accurately measure the absorbed dose using materials that closely match the stopping power of human soft tissue, (2) separate the effects of charged particles and neutrons, and (3) be used in the vacuum of space.

Space qualified radiation dosimeters, developed for Space Shuttle and International Space Station (ISS) missions, have now exceeded their design life and do not satisfy the radiation monitoring requirements of long-duration missions into deep space [9–11]. More importantly, none of those instruments have been designed to actively monitor exposure to neutrons which have a high relative biological effectiveness, can affect blood-forming marrow in bones, and may account for up to 20% of the total radiation dose received by astronauts on the ISS. To overcome these limitations, we have designed the Charged & Neutral Particle Tissue Equivalent Proportional Counter (CNP-TEPC), which is a radiation dosimeter capable of separating the dose from charged and neutral radiation in real-time. Since 2017, the HASP program has played a major role in the development of the CNP-TEPC instrument by enabling our team to test various iterations of the mechanical and electrical hardware aboard a stratospheric balloon at altitudes greater than 120,000 feet and for flight durations that could exceed 10 hours.

During HASP 2019, we propose to fly in the small payload category and further the progress of previous mission in preparation for our upcoming flight aboard NEUDOSE (www.mcmasterneudose.ca), a Canadian Space Agency funded CubeSat, in 2021-2022. The technical and scientific objectives for our proposed flight during HASP 2019 are to:

- demonstrate stable operation of <u>all</u> CNP-TEPC subsystems in a near-space environment
- transmit CNP-TEPC spectral data using our previously developed and flown UHF/VHF communications module and verify with the HASP communication interface
- measure altitude variations in dose and quality factors of charged and neutral radiation

1.2 Principle of Operation

The CNP-TEPC is an advanced radiation monitoring instrument developed to measure, in real-time and for the first time, the microdosimetric spectra of charged particles and neutrons that could pose serious health threats to astronauts during future manned missions into deep space. The CNP-TEPC instrument, shown in Figure 1, consists of two detector technologies combined to enable real-time separation of absorbed dose and quality factors from charged particles and neutrons. The first component is a spherical Tissue Equivalent Proportional Counter (TEPC), which has an isotropic response, and it is the central component which enables real-time radiation dosimetry as it records the lineal energy distribution of incident radiation. The lineal energy distribution can then be used to calculate the absorbed dose and estimate the mean quality factor of radiation. However, since the TEPC is sensitive to all ionizing radiation, the measured lineal energy distribution often consists of a complex mixture of charged particle and neutral interactions which are difficult to separate. To separate the neutral component of lineal energy from that produced by charged particles, the CNP-TEPC instrument implements an Anti-Coincidence Detector (ACD) that surrounds the spherical TEPC and provides a trigger signal whenever charged particles traverse it. This technique is often adopted in space borne gamma- or x-ray instruments to eliminate the charged particle background and is based on the fact that all charged particles traversing the spherical TEPC detector must also traverse the ACD. On the other hand, neutrons and other neutral particles will deposit their energy in either the TEPC or the ACD, but typically not both.

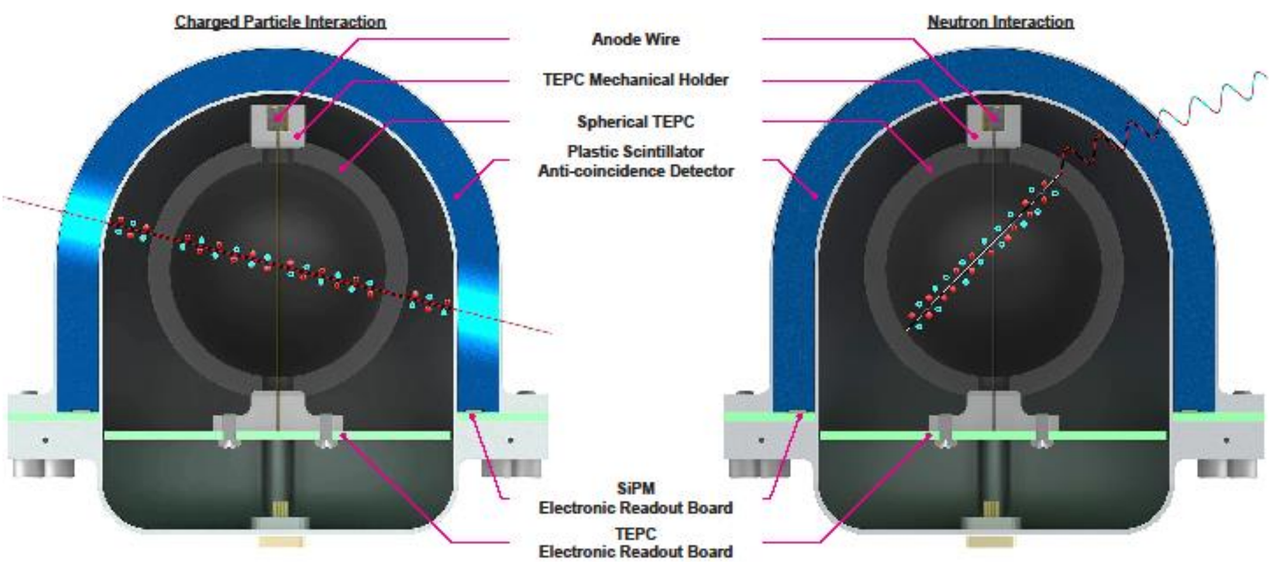

Figure 1: *The CNP-TEPC instrument separates the dose from charged particles and neutrons by monitoring the signal from a hemispherical plastic scintillator Anti-Coincidence Detector (ACD) which surrounds a spherical TEPC detector. When charged particles interact with the instrument, shown on the left, they simultaneously deposit energy in the ACD and spherical TEPC. However, neutron interactions, shown on the right, deposit energy in one or the other, but typically not both.*

2. Payload Specifications

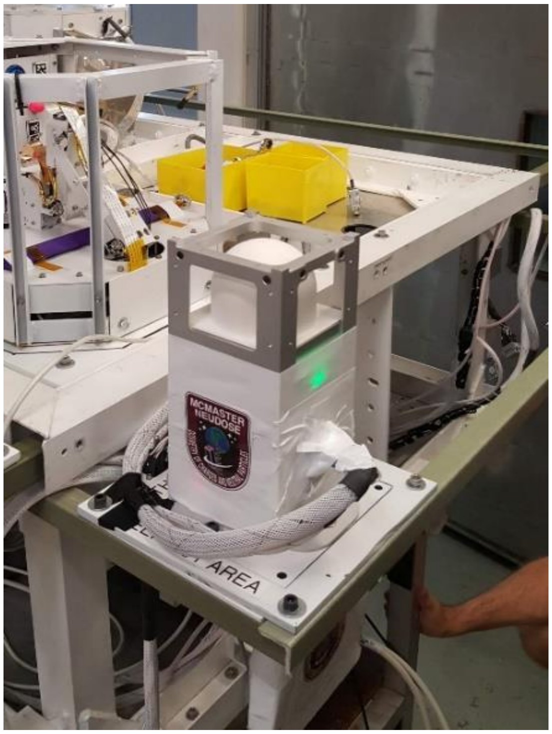

Figure 2: *A picture of our 2018 payload integrated with the HASP platform following a successful thermal vacuum chamber test.*

The small payload that we proposed to fly on HASP 2019 is shown in Figure 2 and is mechanically identical to the payload flown during the HASP 2018 flight campaign. Our HASP 2019 payload consists of the following major subsystems:

- the CNP-TEPC instrument – which will be mechanically the same as during HASP 2018 but with updated electronics hardware and firmware
- the power distribution module (PDM) – which will be the same as during HASP 2018
- the communications module (COMM) – which was successfully tested during the HASP 2018 thermal vacuum tests but disabled during flight

Our HASP 2019 payload will be 22.7 cm tall and occupy a 14.5 cm × 14.5 cm footprint on the supplied HASP mounting plate. In this configuration, the total mass of the payload is 1.8 kg and remains well within the 3 kg margins for the HASP small payload specifications.

2.1 CNP-TEPC

Central to the CNP-TEPC instrument is a spherical TEPC detector that has a wall made of electrically conductive A-150 tissue equivalent plastic and inner and outer diameters of 40 mm and 48 mm, respectively. The A-150 plastic is biased to a high voltage potential of -1000 V, producing an electric field inside the detector. A thin anode wire (25 – 50 μm), held at ground potential, runs through the center of the spherical TEPC and collects the ionization charge produced when radiation events traverse the sensitive volume. The entire TEPC assembly is mechanically supported by an electrically insulating holder that is mounted to the TEPC electronic readout board and housed in a 1 mm thick aluminum pressure vessel. The opposite side of the electronic readout board houses a charge sensitive preamplifier circuit that extracts the small electrical pulses, and a barometric pressure and temperature sensor. The pressure

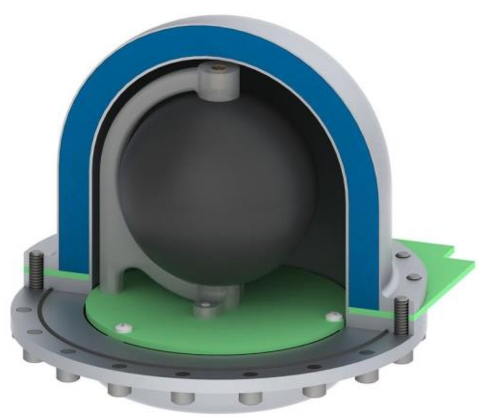

Figure 3: *A rendering of the CNP-TEPC instrument assembly. The spherical TEPC detector, made of A-150 plastic and filled with tissue equivalent gas, is surrounded by a holder mounted to the DAQ board. The entire container is contained in a 1 mm thick aluminum pressure vessel.*

vessel is sealed by an indium o-ring and filled with low pressure (20 – 30 torr) propane-based tissue equivalent gas. Propane-based tissue equivalent gas, composed of 55% C_3H_8, 39.5% CO_2, and 5.5% N_2, is one of the most commonly used tissue equivalent gas mixtures. At an internal pressure of approximately 20 Torr, the spherical TEPC simulates 2 μm of adipose tissue and enables measurement of the lineal energy distribution of incident radiation in the range of between 0.1 keV/μm to 1,000 keV/μm. The entire assembly is shown in Figure 3.

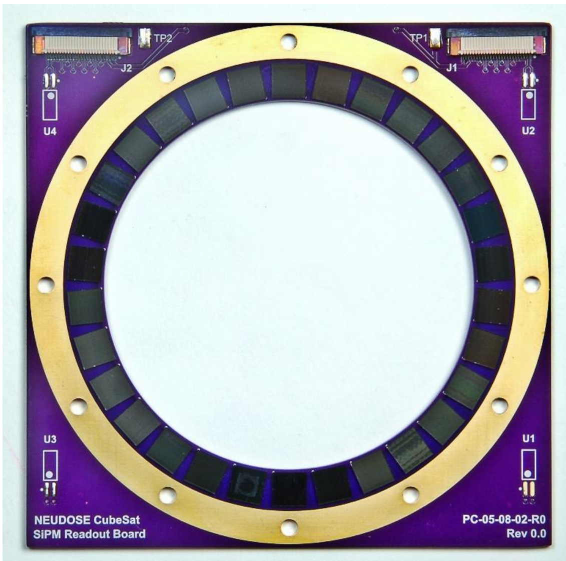

Figure 4: *Photograph of the SiPM carrier module which houses 30 SiPM sensors, arranged in an evenly-spaced circular configuration, and 4 temperature transducers to compensate for temperature dependent gain variations.*

Discrimination of charged and neutral radiation is achieved by monitoring the ACD system for trigger signals that are produced in coincidence with TEPC signals. The ACD, which surrounds the spherical TEPC, consists of an 8 mm thick plastic scintillator that is shaped into a hemisphere and directly coupled to an array of SiPMs that collect the scintillation light. The plastic scintillator is mounted external to the TEPC pressure vessel and fixed in place by a covering lid which provides a light tight environment. The SiPMs are arranged in an evenly-spaced circular configuration and mounted on the SiPM carrier module shown in Figure 4. This circular arrangement leads to an instrument response that is sensitive to the incident angle of charged particles. SiPMs are well suited for this application as they provide performance similar to photomultiplier tubes, but in a smaller and less massive package. Moreover, they feature high gains ($\sim 10^6$) at low operating voltages (typically 20 – 70 V) and can be operated in the vacuum of space. A power supply biases the SiPMs and is automatically adjusted to compensate for temperature dependent gain variations, as measured by four temperature transducers on the SiPM carrier module.

2.2 Data Acquisition Module

The data acquisition module (DAQ) processes the output signals from the TEPC and ACD subsystems and will be a new revision that incorporates the following lessons learned from HASP 2018:

- implementation of high-side voltage monitoring, current monitoring, and noise filtering for the TEPC and SiPM high voltage power supplies
- adjustment of the $\Delta V/\Delta T$ slope for the temperature sensors to fit within the dynamic range of the housekeeping ADCs
- completion of the TEPC preamplifier, amplifier, and readout circuitry
- implementation of MicroBlaze softcore within the FPGA to handle the housekeeping and data storage tasks for the instrument

In order to monitor the status and output of the TEPC, the main functions of the DAQ are to condition and digitize the small amplitude signals from the TEPC preamplifier, as well as provide temperature and pressure information for gas density calculations. The output of the charge sensitive preamplifier, which is housed inside the pressure vessel and near the TEPC, is used as input signal to a digital pulse processing circuit. A fast ADC on the DAQ continuously digitizes the output pulses from the preamplifier circuit at a rate of 80 MSPS and streams the digitized values in to an FPGA where a digital pulse processing algorithm is implemented. The algorithm processes the ADC data stream using a pipeline architecture to generate real time digitally shaped pulses. There are two parallel digital signal processing chains inside the FPGA which are optimized to extract different information from the TEPC detector. One chain, labelled 'slow', processes the ADC samples through a digital filter which has a long shaping time constant, optimized for accurately measuring the pulse amplitude which is proportional to the energy deposited by particles inside the TEPC. The other chain, labelled 'fast', processes the ADC samples through a digital filter with a short shaping time constant, optimized for accurately measuring the arrival time of pulses.

The DAQ also contains all the front-end electronics necessary to read out the up to 32 SiPM sensors used by the ACD subsystem of the CNP-TEPC instrument. Analog output signals, from the SiPM carrier module, are routed to the SiPM DAM using a pair of Samtec FFC connectors where they are pre-amplified and analyzed by a 32-channel front end ASIC with configurable gain, fast shaping and slow shaping with configurable peaking times, and peak sensing capability. The fast-shaped signals are internally discriminated on the front-end ASIC against a programmable threshold, producing 32 individual digital timing signals that can be used for event triggering. These 32 digital signals are routed to a Xilinx Spartan 6 FPGA, where they are incorporated into the coincidence, event triggering, and particle direction logic. Additionally, the amplitude from each analog channel (i.e. SiPM) is individually sampled by sample-and-hold circuitry and multiplexed to a dual-channel 2 MSPS ADC connected to the Spartan 6 FPGA.

2.3 Communications Module & Commands

The communications module is designed to transmit spectral data from the CNP-TEPC instrument to the receiving ground station on Earth and receive commands from the ground station. The communications module will receive information from the DAQ and organize the information into packets suitable for transmission using radios. Table 1 displays the serial data structure of the data.

Byte(s)	Hex Value	Description
2		TEPC Pressure (Start of Acquisition)
2		TEPC Pressure (End of Acquisition)
2		TEPC Temperature (Start of Acquisition)
2		TEPC Temperature (End of Acquisition)
2		TEPC High Voltage (Start of Acquisition)
2		TEPC High Voltage (End of Acquisition)
2		TEPC Threshold
2		SiPM Temperature (Start of Acquisition)
2		SiPM Temperature (End of Acquisition)
2		SiPM High Voltage (Start of Acquisition)
2		SiPM High Voltage (End of Acquisition)
2		SiPM Threshold
2		Live Time (in centiseconds)
2		Real Time (in centiseconds)
125		GPS String (Start of Acquisition)
125		GPS String (End of Acquisition)
2	0A0A	Start of Anti-Coincidence Spectrum Data
2		ACOINC CH0 Counts
2		ACOINC CH1 Counts
2		ACOINC CH2 Counts
		⋮
2		ACOINC CH16382 Counts
2		ACOINC CH16383 Counts
2	0B0B	Start of Coincidence Spectrum Data
2		COINC CH0 Counts
2		COINC CH1 Counts
2		COINC CH2 Counts
		⋮
2		COINC CH16382 Counts
2		COINC CH16383 Counts
2	0C0C	End of Spectrum Data
4		32- bit Cyclic Redundancy Check (CRC)

Table 1: *The serial data structure of each record byte*

The CNP-TEPC payload produces two spectra of data, stored as 2-byte values in 16,384 channels, which make up most of the data produced. Including 6 start and stop bytes, each dataset will have 28 bytes of 'housekeeping' data, 2 GPS measurements at 125 bytes each, and 4 bytes of Cyclic Redundancy Check (CRC) information, making each transmitted file 65.824 kB in size. Spectra will be collected every 10 minutes, requiring 110 bytes/s to be transferred. Using the 8-N-1 encoding scheme, the required downlink will be 110 bytes/s · 9/8 · 8 bits 1 byte = 988 bits/s. This falls significantly below the upper limit of 1200 bps. The data is also going to be stored locally on the payload, to test the data storage and recovery capabilities of the CNP-TEPC.

The communications module is designed to transmit spectral data from the CNP-TEPC instrument to the receiving ground station on Earth and receive commands from the ground station. Additionally, it will transmit payload health information to monitor the runtime of the onboard systems. The communications module will receive information from the DAQ and organize the information into packets suitable for transmission using radios. For transmission, a CC1125 UHF transceiver (435 MHz, ~200 kbit/s) will be used, and a VHF transceiver will be used for receiving commands (145 MHz, 1200 bit/s). The use of the higher-frequency UHF band allows for faster data throughput rates, which will allow for the transmission of large amounts of science data in a more time-effective manner. The use of the VHF band allows for a more robust signal to be received by the payload, as it is less attenuated by the atmosphere. Additionally, the separate bands for transmission and reception allow for full-duplex capability of the radio systems.

The two discrete commands, "*Power On*" and "*Power Off*", will be accepted by the PDM and handled accordingly. In addition, serial commands to toggle the radio on and off will be utilized. Functional tests of the communications module will be performed during the HASP flight. For example, the UHF system is expected to send data at a rate of up to 250 kbit/s, while the VHF system is expected to receive data at a rate of 9600 b/s. We will be sending different commands to the payload to establish communications, and eventually be able to send commands to receive the science data for further analysis. The data collected using the communications module will be compared with the data collected from the HASP interface for verification.

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2.4 Power Distribution Module (PDM)

Figure 5 shows the power block diagram for the payload. As in HASP 2017 and 2018, the payload will be powered directly from the HASP bus using a dedicated PDM that will regulate, monitor, filter, and supply the analog and digital voltages required by the CNP-TEPC electronics and front-end electronics. The system architecture of the PDM used a direct conversion architecture, where high efficiency LT8610 switching regulators are used to step down the 30 V HASP bus to the intermediate value of 12 V for the CNP-TEPC instrument and 5V for the communications module. The 12 V intermediate power rail was split into separate analog and digital voltage rails where the required voltages is

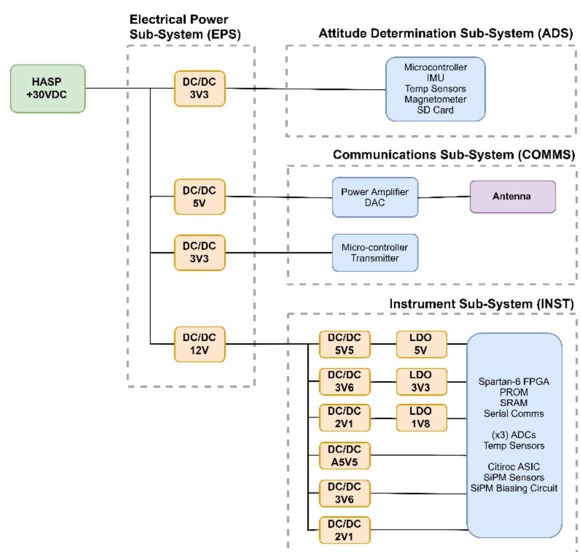

Figure 5: *Power flow and system block diagram of the electrical distribution system.*

once again generated using high efficiency switching regulators.

The payload will interface with HASP in a similar manner as the previous payload. The EDAC pins to be used are +30VDC (A, B, C, D) and Power Ground (W, T, U, X). Since there is no plan to utilize the analog download interface lines nor the discrete command interface lines contained within the EDAC connector, the remaining pins of this header will be capped off as no-connects. The DB9 serves as the primary data port between the payload and HASP. The three lines (Tx, Rx, Signal GND) belonging to the pigtail will be grouped together with the eight power supply lines to a single DB15 connector. This will interface directly to a port receptacle/header on the exterior side paneling of the instrument.

2.5 Power Draw

As we experienced in HASP 2018, the inclusion of the communication module added significantly to our power draw, however, we remained well within the 0.5 A limit allotted to small payloads.

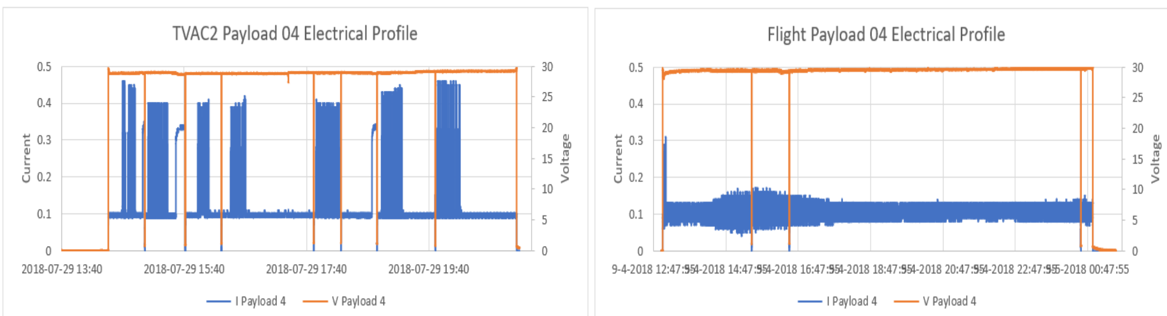

Figure 6: *Plots of the voltage and current measurements during the 2nd thermal vacuum test (left) and flight portion of HASP 2018.*

As shown in Figure 6, our payload drew an average of 3 W during nominal flight operations and a maximum of 14 W while it was transmitting data via the communication module during 2nd thermal vacuum test. The radio was kept powered off for the flight and no other large power draws were recorded by the HASP telemetry. A notable observation is the 0.1 A ripple current that occurred during the payload's flight. This magnitude was not seen during the previous TVAC tests and the cause of the 3 W fluctuation will need to be further investigated in 2019.

2.6 Mass Budget

The mass budget remains very similar to our HASP 2018 payload and can be found in Table 2, showing allotted mass budgets and estimated/measured weights for each component. The errors on estimated weights were taken to be 10% of the value. The current mass estimate for the entire payload is 1810 ± 70 g, well below the required mass limit of 3000 g. Each component of the payload is also below its allotted mass limit, not including the 400 g reserved for re-allocation if necessary.

Table 2: *The mass budget for the HASP 2019 payload. Estimated masses include a 10% error estimate.*

COMPONENT	ALLOTTED MASS (G)	ESTIMATED MASS (G)
HOUSING AND MOUNTING	500	220 ± 20
CNP-TEPC HOUSING	500	340 ± 30

CNP-TEPC INTERNALS	700	500 ± 50
PDM	200	100 ± 10
DAQ	200	100 ± 10
COMMUNICATIONS MODULE	200	100 ± 10
HARDWARE	300	200 ± 20
TOTAL	**2600**	**1810 ± 70**
EXTRA	400	1190

2.7 Mechanical Housing & Mounting Plate Footprint

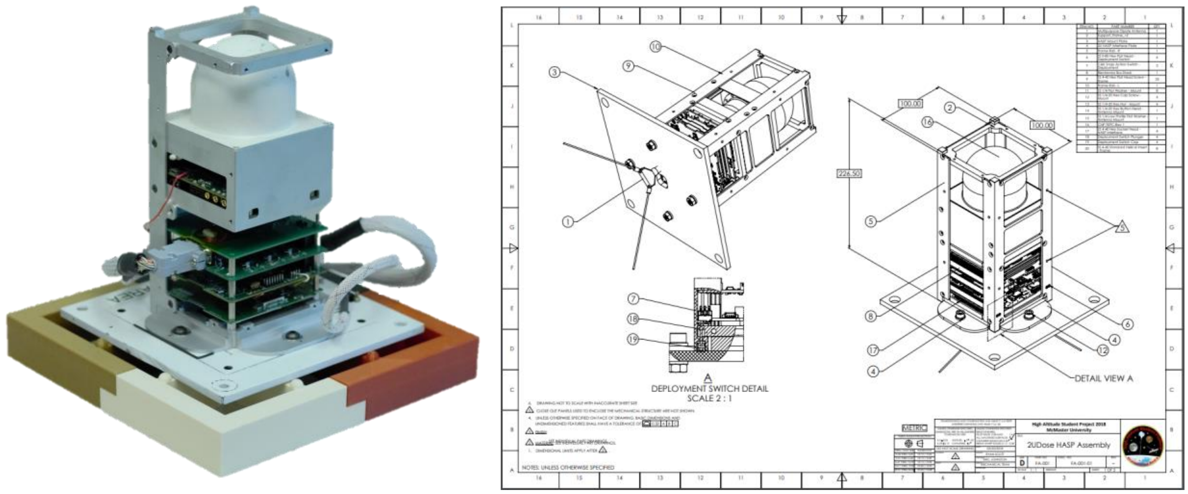

Figure 6: *(Left) An image of the HASP 2018 payload, which will remain the same for HASP 2019, and (Right) drawings of the mechanical housing and assembly attached to the HASP mounting plate.*

The HASP 2019 payload will have the same footprint as the HASP 2018 payload. All circuit boards will be mounted to the aluminum housing and is constrained to a 10 cm x 10 cm footprint. Four mounting bolt holes surround the outside of the instrument allowing for interfacing with the HASP mounting plate. The payload does not exceed the allowed 30cm height and we do not have a preferred orientation. Figure 6 shows the HASP 2018 payload with the instrument access gate open to display internal components.

2.9 Risk Assessment & Mitigation Plan

There are two potential risks noted with the payload, high voltage arcing and a pressurized vessel. These two potential risks have been carefully examined and a plan to mitigate them is outlined in the following sections. Both risks are necessary for the function of the CNP-TEPC, and as such, there is no way to eliminate them entirely. However, as will be shown, there has been significant planning to ensure that these two risks are not a concern. Additionally, thermal issues should be considered.

2.9.1 High Voltage Power Supply

At higher altitudes, the dielectric breakdown of the atmosphere is more likely to occur. To mitigate the risk of arcing, the high voltage power supply of the instrument will be encapsulated in a compound with high dielectric strength. This process is called potting. The recommended practices in a technical note published by NASA will be followed [12]. To summarize, a compound with high dielectric strength such as Emerson and Cumming's Stycast 1266 high voltage potting compound, or a similar compound whose physical, mechanical, and thermal characteristics are compatible with the high voltage supply, will be chosen. During mixing and casting of the HVPS, the encapsulant compound will be subject to thermal vacuum degassing to remove the risk of any void in the encapsulation wherein electrical breakdown could occur. The potted assemblies will be taken through several extreme temperature cycles, ranging between -20^{o}C and +50^{o}C. This aggressive thermal cycling helps aggravate differential thermal expansion between the board and the potting compound, hence ensuring any flaws in the potting process are caught before flight. The potted assemblies will then be powered at maximum high voltage in a vacuum chamber and monitored at varying temperatures. Through this process, the risk of any arc faults occurring will be mitigated prior to HASP integration.

2.9.2 Pressure Vessel

The CNP-TEPC requires a specific internal pressure in order to function properly. Since this constitutes a pressurized vessel, a Finite Element Analysis (FEA) was used to determine a safe pressure vessel design. The FEA included two different scenarios, both with atmospheric pressure outside (which simulates the case on the ground, the largest pressure differential) and the pressure vessel internal pressure at 30 torr. The two FEAs were the cases of the 10G vertical shock and the 5G horizontal shock tests. The results of the 10G vertical FEA can be found in Figure 5 on the left side, and the results of the 5G horizontal shock FEA are shown on the right. Overall, the lowest factor of safety is 5.8. This should ensure the pressure vessel will survive the entire balloon flight.

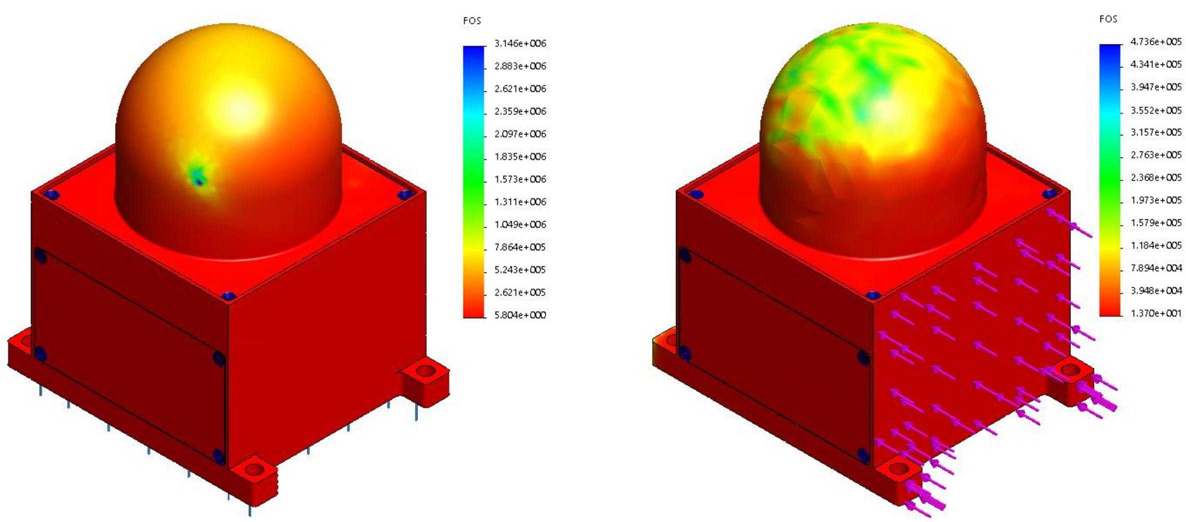

Figure 6: *Factor of safety for the 10G vertical shock FEA (left) and 5G horizontal shock FEA (right), including the pressurized vessel with atmospheric pressure. The lowest factor of safety was found to be 5.8.*

2.9.3 Thermal

From our experience during HASP 2018, we do not anticipate any thermal issues during thermal vacuum testing or flight, due to the low power density of the payload. To minimize solar radiance, the payload will again be painted with a thin coat of white paint. This should greatly reduce the power absorbed by the sun, ensuring overheating is not an issue. Additionally, removable closeout panels will be mounted to the mechanical structure to reduce solar radiance on the communication and main power distribution modules. The HASP 2017 and 2018 instruments did not experience any thermal issues, and it is not expected for this mission.

2.10 Anticipated Integration & Flight Operations

The CNP-TEPC has been designed for autonomous operation and minimal operations during integration and throughout flight is expected. During integration, we require the payload to be bolted to the mounting plate and the serial and power connectors to be attached. All other assembly of the payload will be done prior to integration with the HASP balloon. We anticipate the following steps for successful payload integration:

1. Provide the latest payload mechanical and electrical interface control documents.
2. Pre-integration inspection to confirm HASP compliance (mass, voltage, and current).
3. Test instrument power up using HASP bench test hardware.
4. Test instrument telemetry using HASP bench test hardware.
5. Mount instrument to HASP platform.
6. Test instrument power up using actual HASP flight hardware.
7. Test instrument telemetry using actual HASP flight hardware.
8. Perform pre-flight thermal vacuum testing.
9. Test instrument communications throughout flight. Verify with HASP interface.

During flight, the CNP-TEPC will operate autonomously and send a full dataset using the serial downlink every 10 minutes. Serial commands will be utilized to turn the radio on and off when appropriate.

3. Team Structure and Project Management

Luis Lopera will act as the student team leader, where his management duties include submission of monthly status reports, attending and documenting teleconference calls, documentation, and liasing between the student group and the 4 faculty and industry advisors. Mr. Lopera has participated in both the HASP 2017 and 2018 flight campaigns and will also lead the development, integration, and testing of the CNP-TEPC instrument.

Leading the mechanical structure team is Luis Tallavo. His duties include the design, construction, and integration of the payload structure. Mr. Virani will ensure the appropriate interfacing of all components of the payload.

Alex Melnichuck leads the power team. His duties include the design, construction, and testing of the PDM to ensure that the electrical demands of every component of the payload will be handled accordingly.

Jimmy Nguyen leads the communications team. His duties include the design, construction, and integration of all communication hardware, antennas and ground-station. Mr. Nguyen will ensure that successful communication will be established between the payload and ground-station.

The project will receive guidance and funding from 4 faculty and industry advisors who will also be in communication with the group on a weekly basis. The 4 advisors are:
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- Dr. Andrei R. Hanu, a senior scientist at the Bruce Power Nuclear Generating Station and an adjunct assistant professor in the Department of Physics & Astronomy at McMaster University. Dr. Hanu developed the CNP-TEPC instrument and NEUDOSE mission concepts and will provide guidance pertaining to the development of the mission and the science instrument.
- Dr. Soo-Hyun Byun, a professor in the Department of Physics & Astronomy at McMaster University. Dr. Byun will provide technical and theoretical guidance pertaining to the science instrument development.
- Dr. Eric Johnston, a research scientist at Bubble Technology Industries Inc. and former HASP program student.
- Dr. Stanley Hunter, from the Astroparticle Physics Laboratory at NASA's Goddard Space Flight Center, provide expert advice and technical assistance for the entire payload system.

The HASP team and roles are outlined in Table 3.

Table 3: *HASP team members, roles, and student statuses.*

NAME	ROLE	STUDENT STATUS
LUIS LOPERA	Student Project Lead	Graduate Student
LUIS TALLAVO	Mechanical Lead	Undergrad
ALEX MELNICHUCK	Power Lead	Graduated
SEHAZ DAYAL	TEPC Team	Undergrad
WILLIEM AGNIHOTRI	TEPC Team	Undergrad
MALCOLM HODGINS	ACD Team	Undergrad
JORDAN COWAN	DAQ Team	Graduated
JAY KOSHI	DAQ Team	Undergrad
ERIC DYER	DAQ Team	Graduated
BHAVESH KAKWANI	DAQ Team	Graduated
JOE PERRI	DAQ Team	Undergrad
SIDDEST BIST	DAQ Team	Undergrad
JUAN TALLAVO	Mechanical Team	Undergrad
AMY LING	Mechanical Team	Undergrad
RUBY YEE	Mechanical Team	Undergrad
NEIL VIRANI	Mechanical Team	Undergrad
SAMUEL PRASAD	Mechanical Team	Undergrad
LAILA NASIR	Science & Data Management Team	Graduate Student
DEVIN BURKE	Science & Data Management Team	Graduate Student
THOMAS DOMINGO	Science & Data Management Team	Graduate Student
MICHEAL PUPULIN	Science & Data Management Team	Undergrad
JIMMY NGUYEN	Communications Team	Graduate Student
AARON PITCHER	Communications Team	Graduate Student

The student group meets weekly and with at least one advisor on a weekly basis. In addition, the team maintains active communication and consistent documentation through web interfaces such as Slack and Confluence.

It is anticipated that roughly 11 members and 2 advisors will attend integration and testing at the CSBF in 2019. The same 13 individuals are expected to participate in flight operations at Ft. Sumner in 2019.

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