HASP Student Payload Application for 2016

Payload Title: Hazardous Gases for Harsh Environments LED Sensor

Payload Class: (check one) ☐ Small ☒ Large	Institution: University of Central Florida	Submit Date: Dec. 18, 2015

Project Abstract

A robust and low-cost CO/CO_2 sensor has been developed for the applications of an enhanced early fire hazard detection sensor for space vehicles. However, is desirable to extend the sensor to environments outside the human habitable area of the vehicle so that the technology may be used to detect other threatening events such fuel leaks or other gas ventilation. In order to validate the technology for its suitability in this area the sensor developed for CO/CO_2 measurements will flown to high altitudes where it will encounter like conditions to these harsh environments.

Team Name: University of Central Florida	Team or Project Website:

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1. Payload Description

This is a proposal to fly a package on the 2016 HASP mission which will demonstrate the base technologies for a series of hazardous gas sensors to be operated in harsh environments. These sensors function using low-cost and low-power light emitting diodes (LEDs) in the mid-inferred (MIR) spectral range under the operating principles of direction absorption spectroscopy which provide time-resolved measurements of the targeted gas at the parts per million (ppm) level. These instruments are designed to fly on space vehicles which may include manned, unmanned, low Earth orbit (LEO), interplanetary (missions to Mars), and space stations. The environments encountered on these vessels will vary, from having to support human life to the vacuum of space, and the spectrum in-between. The balloon flight will give us access to relevant conditions (sustained low pressures and temperatures) and allow us to demonstration autonomous operation of the sensor. Additionally, there will be a moment of zero-g when the system is released from the balloon before the parachute is deployed in which we can evaluate performance in microgravity conditions.

The current sensor design targets CO and CO_2, which are trace gases that increase in the presence of smoldering/burning materials, and is intended as an enhanced early fire hazard detection sensor for space vehicles. This sensor was designed and collaboration and funded, in part, by the Federal Aviation Administration, under the Center of Excellence Commercial Space Transportation (FAA COE CST) research structure. The sensor to be flown was designed for human habitable environments, however the technology series is intended to be extended beyond this environment which must to be shown. With compact, economical, low-power sensors that are able to continually monitor gases that are characteristic of burning materials, a distributed sensor array could be implemented on space vehicles that would allow early detection of fires, gas leaks, or other critical events. Future sensors using this technology will target additional gases such as RP1, methane (CH4), ammonia (NH3), polymer vapors, and other expected vented or generated gases of space vehicles. Figure 1 shows the absorption features of some of the gases that can be targeted by these MIR LEDs.

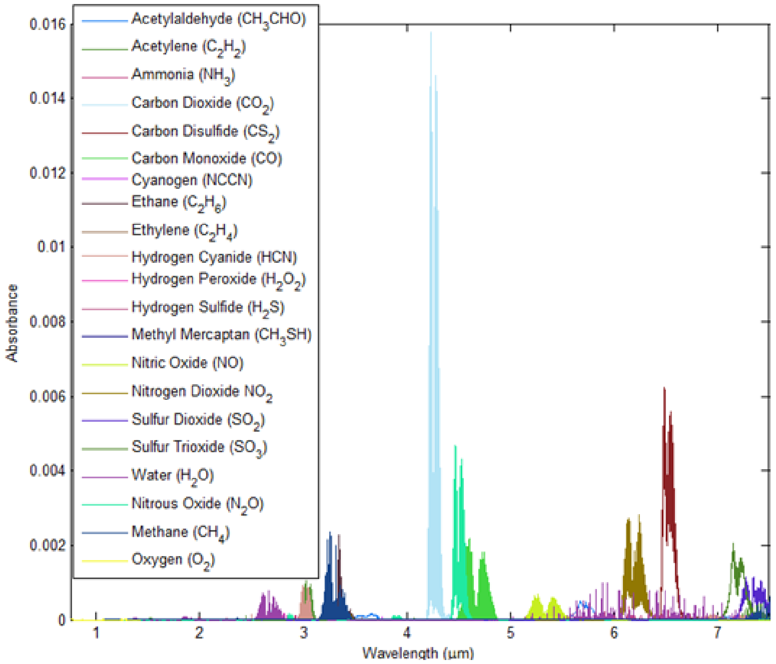

Figure 1: Several gases that are within the spectral region of available MIR LEDs.

1.1 Motivation

This sensor falls under the Federal Aviation Administration Center of Excellence Commercial Space Transportation (FAA COE CST) Research Areas 3.3 and 3.4 in regards to the ECLSS as well as emergency conditions [1]. With the increasing likelihood that space tourism will develop into a viable industry, the number of launches into space will increase. The FAA and the pioneers in the space tourism industry have expressed an interest in a durable, sensitive sensor that is cost-effective, and has low power consumption. Before space tourism can begin bringing crews and consumers into space, the FAA must be assured that all safety standards are met, including the fire detection and suppression systems.

1.2 Principles of Operations

Absorption spectroscopy can target a molecular species by its characteristic absorption spectrum. In species concentration measurement, a collimated beam of light with a wavelength characteristic to the targeted species is directed through a gas. The attenuation of the beam is measured by comparing the incident and transmitted radiation, which is related to molecular concentration. Absorption spectroscopy follows from the Beer-Lambert law (equation 1) which relates the transmitted intensity I to the incident intensity I_0 when a spectrally narrow radiation at frequency $\nu[\mathrm{cm}^{-1}]$ is directed through a gas medium:

$$T_\nu = \left(\frac{I}{I_0}\right) = \exp(-S\phi P x_i L), \tag{1}$$

Here T_ν is the transmissivity, $S(\mathrm{cm}^{-2}\,\mathrm{atm}^{-1})$ is the line strength, $\phi(\mathrm{cm})$ the line-shape function, $P(\mathrm{atm})$ is the total pressure, $L(\mathrm{cm})$ the line path length through the gas, and x_i the mole fraction of the absorbing species. The product $k_\nu = S\phi P x_i$ is known as the spectral absorption coefficient. The line strength was generated using the HITRAN 2012 database, which provides a compilation of spectroscopic parameters used to predict and simulate the transmission of light in the atmosphere [2].

1.3 Payload Description

The instrument to be flown was originally developed by the team lead, Kyle Thurmond, as a senior design project in 2013, developed in labs at UCF and ORNL, and has been evaluated for performance and calibrations [3]. An early version of this sensor is shown in figure 2 below. The sensor utilizes three LEDs, one centered at 3.6μm to serve as a reference (I_0 in Beer's law), one center at 4.2μm for measuring CO_2, and one centered at 4.7μm for measuring CO. The three LEDs are individually spectrally filtered and spatially collimated; then combined into a single beam to be transmitted through the gas under investigation. After being transmitted through the gas the beam is focused onto a single detector. Each LED's amplitude is modulated at a different frequency so they can be separated by Fourier transform. With this information and a variation of Beer's law we can derive the concentration of CO and CO_2.

Neat gas calibration measurements were made in both an 8cm long line-of-sight calibration cell in order to obtain calibration curves and determine the sensitivity of the sensor to CO_2 and CO [3]. Simultaneous measurements of CO and CO_2 were also completed so to characterize possible cross-interferences between the species. Additionally, time resolution measurements were performed to demonstrate sensor speed and determine the fastest transients the sensor can resolve. The sensor was evaluated to have a detectability limit of 30ppm for CO_2 and 400ppm for CO with no observed cross-interference. The signal is well resolved for fluctuations up to 250Hz. The detectivity limit for CO is being improved so that 10ppm levels are possible by increasing the power to the LEDs and using a multipass cell to increase the path length.

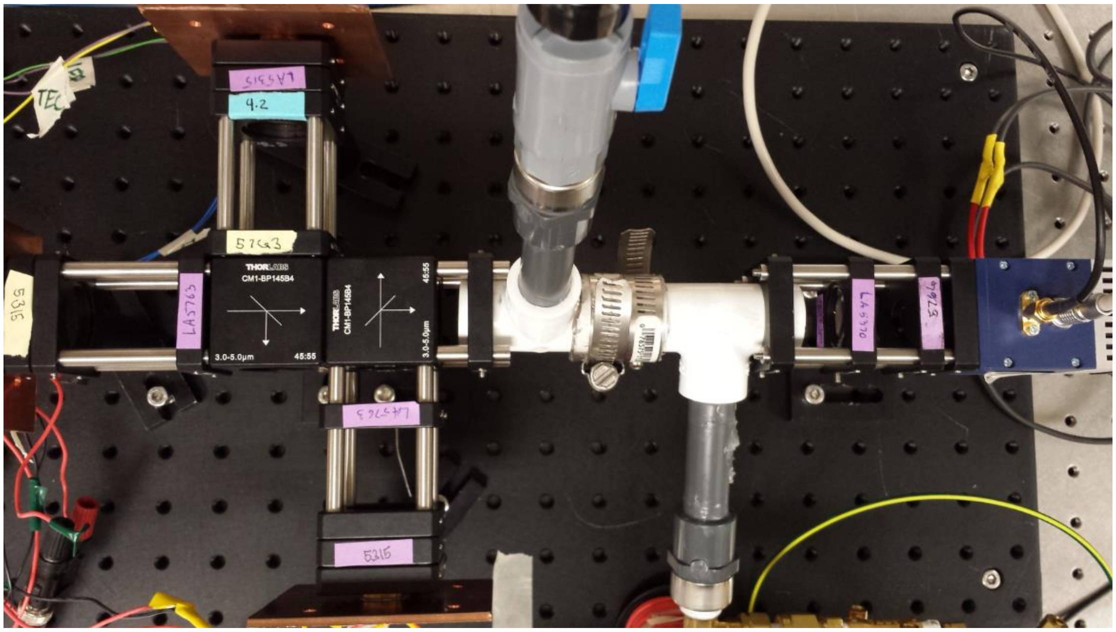

Figure 2: Early version of the sensor to be flown in lab setting. LEDs are on the left and the detector is on the right with a PVC flow cell in between.

Development will be made to make the technology ready for flight by taking steps to prevent optical misalignment, optimize thermal management, and protect vulnerable electronics from the environment and EMI from the balloon or other payloads. The payload will consist of an aluminum box with the sensor mounted to the exterior. The box will contain the driving electronics and a National Instruments cRIO DAQ necessary to operate the experiment in flight. A critical development during this phase will be the sensor thermal management design. The different components of the sensor all have their individual optimal operating temperatures so are equipped with thermal electrical coolers (TECs). The temperatures encountered at these altitudes are actually much lower than the optimal temperature for these components, fortunately, though, these TECs may be operated in reverse. Simulations and special considerations will be given to ensure optimal performance in these extreme conditions. During this development the sensor and balloon package will be tested in a simulated environment in order to reduce the likeliness of failure during the actual flight. An environmental chamber that can produce conditions close those encountered at 36km, -20°C and 13mbar, will be used to test the system. A summary of these challenges are listed in table 1 below.

Table 1: Anticipated challenges, probability, impact, and current mitigation strategies.

#	Issue	Probability	Impact	Mitigation
1	Low temperature thermal failure/cold soak	Medium	Medium	-Sensor components are equipped with TECs which can cool and heat as needed. -Driving electronics will be insulated and self-heating.

2	Overheating due to lack of convection	Medium	High	-Simulations can optimize convective cooling in thin atmosphere conditions. -Radiative cooling can supplement.

As was mentioned above, the payload consists of an aluminum box with the sensor mounted to its exterior. The aluminum box is constructed of 0.05in. aluminum sheet and fortified with 1x1in. hallow aluminum construction tubing. A CAD model of the skeletal frame of the aluminum box is shown below in figure 3. This figure also shows the cRIO DAQ mounted inside the frame and a panel where the sensors driving electronics and power control circuitry will be mounted. The bottom of the frame contains a series of holes that will continue through the aluminum box and will be used to secure the package to the HASP.

The NI cRIO DAQ will be used for data logging and experiment control. This DAQ was chosen to allow for multiple sensor inputs (photodetector, thermocouples, barometer, etc.) and analog output for controlling LED function output.

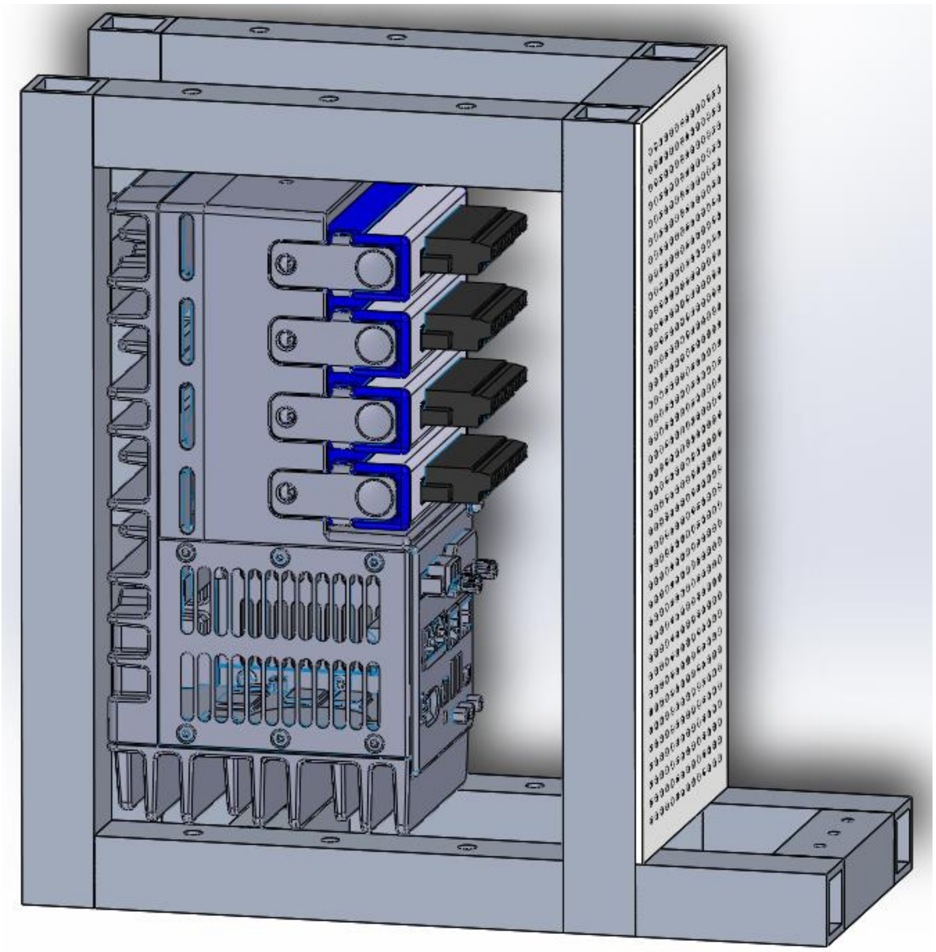

Figure 3: Package frame containing the National Instruments cRIO DAQ. The driving electronics will be mounted on the panel on the right. The payload will be secured to the HASP through the through holes at the bottom of the frame.

Once the payload has been powered up it will begin its normal operations and continue to do so through the duration of the flight. A gas cell will have been loaded into the payload precharged with a known gas mixture (N_2/CO_2/CO). This cell will have a membrane so it is always at atmospheric pressure. Once the power is supplied, the sensor will take a measurement of this cell at some predetermined interval. The data will be stored onboard and accessed post flight. No serial uplink/downlink or discrete commands are planned to be implanted for this payload.

1.4 Scientific Objectives

The objectives for this flight will be to: 1) simultaneous measurements of CO and CO_2 at peak altitude (36km), 2) Produce measurements of CO_2 during the moment micro gravity when the package released from the balloon rig and before the parachute is deployed, and 3) demonstrate autonomous operations of the sensor in a flight like environment. Intermediate altitude measurements will also be acquired during flight. The sensor will load will a gas cell charged with N_2/CO/CO_2 at a known ratio which will adjust to the ambient pressure through a membrain.

Success will be defined by successful resolution of CO_2 and CO at peak altitude, maintaining optical alignment, and proper thermal management of the sensor system. The balloon flight will give a smoother flight than other options but we will still have to anticipate vibration and small g-loads. A minor misalignment of the optical train could greatly reduce performance or break the sensor. The most critical test will be thermal management of the sensor. The components of the sensor are temperature-controlled through the TECs, which can either cool or heat as needed. Dissipating waste heat will be difficult in a thin atmosphere as convection will be less effective. Mitigation steps for avoiding failure are discussed in table 1 above.

2. Team Structure and Management

The development of the sensor package will be led by graduate student Kyle Thurmond, who will be assisted by graduate students Justin Urso and Michael Villar. Mr. Thurmond's responsibilities as project manager will include team management, monthly report submissions, and teleconferences. His duties will also include programming the instruments DAQ and experiment design and execution. The instrument will be packaged with a National Instruments cRIO DAQ which will need to be programmed to full automate the sensor and thermal management. For greatest likely of a successful mission, the team will be utilizing an environmental chamber which can simulate conditions close those encountered at 36km, -20°C and 13mbar. The primary knowledge expected to be gained from these experiments is thermal management effectiveness. There is a good possibility that after the first round of testing modifications to the hardware will need to be made so time is planned for this as well as a second round of testing in the chamber. Mr. Urso will take the role of structure engineer which will include the responsibility of readying the hardware for flight while Mr. Villar will take the role components engineer which has the responsibilities of components selections and design. Mr. Urso will need to ensure that the optics will remain properly aligned during the duration of the flight, the package can withstand 10g vertical and 5g horizontal shocks, and that proper thermal connectivity and mass for adequate temperature stability. Mr. Villar will handle pay load driving electronics, support sensors, and interfacing with the HASP. Further support may be recruited from undergraduate students in the University of Central Florida's Mechanical and Aerospace Engineering (MAE) program.

Dr. Subith Vasu is the University of Central Florida faculty advisor for the team and has extensive knowledge of spectroscopic sensors. Dr. Bill Partridge is a distinguished research staff member at

Oak Ridge National Laboratory (ORNL) who has been provided valued expertise since the project was started. Funding is provided by Federal Aviation Administration, under the Center of Excellence Commercial Space Transportation (FAA COE CST).

Table 2: Team personnel, roles, and contact information.

Project Manager	Kyle Thurmond Graduate Student	University of Central Florida	kthurmond@knights.ucf.edu (407) 617-0475
Structure Engineer	Justin Urso Graduate Student	University of Central Florida	justin.urso13@knights.ucf.edu (352) 817-9212
Components Engineer	Michael Villar Graduate Student	University of Central Florida	mvillar@knights.ucf.edu (561) 512-3953
Faculty Advisor	Dr. Subith Vasu Principal Investigator	University of Central Florida	subith@ucf.edu (407) 823-3468
Collaborator	Dr. Bill Partridge Jr.	Oak Ridge National Lab	partridgewp@ornl.gov (865) 850-8592
Collaborator/Sponsor	Nickolas Demidovich	Federal Aviation Administration	Nickolas.Demidovich@faa.gov (202) 267-8437

Table 3 below shows the expected schedule for the project, with milestones in bold. The payload be put under testing as soon as possible (February at the latest) so modifications made if any issues occur. The cycle of testing and corrective actions will take place through the summer until flight preparation is underway. No student participation is anticipated in integration at CSBF or flight operations at Ft. Sumner.

Table 3: Work schedule by month from January of 2016.

	Month											
Tasks	1	2	3	4	5	6	7	8	9	10	11	12
Finalize Hardware Upgrades	**X**											
Program DAQ	**X**											
Thermal Management Analysis	X	**X**										
Complete Calibrations		**X**										
Environmental Chamber Experiments Rounds		**X**			**X**							
Corrective Actions			X	**X**		X	**X**					
Preliminary PSIP Document				**X**								
Final PSIP Document					**X**							
Flight Preparations								**X**				
Flight									**X**			
Reports & Publications										X	X	**X**

3. Payload Specifications

The aluminum box containing the sensitive electronics of the sensor is 12x12x5in. and the sensor is 15x6.8x3.5in, making the box no more than 15x12x8.5. This will classify the University of Central Florida's instrument as a large payload. The payloads structure is constructed of aluminum and acts to mechanically support, shield electronics, and act as a thermal sink to increase the stability of the system. A CAD model of the payload (sensor and support package) is shown below in figure 4.

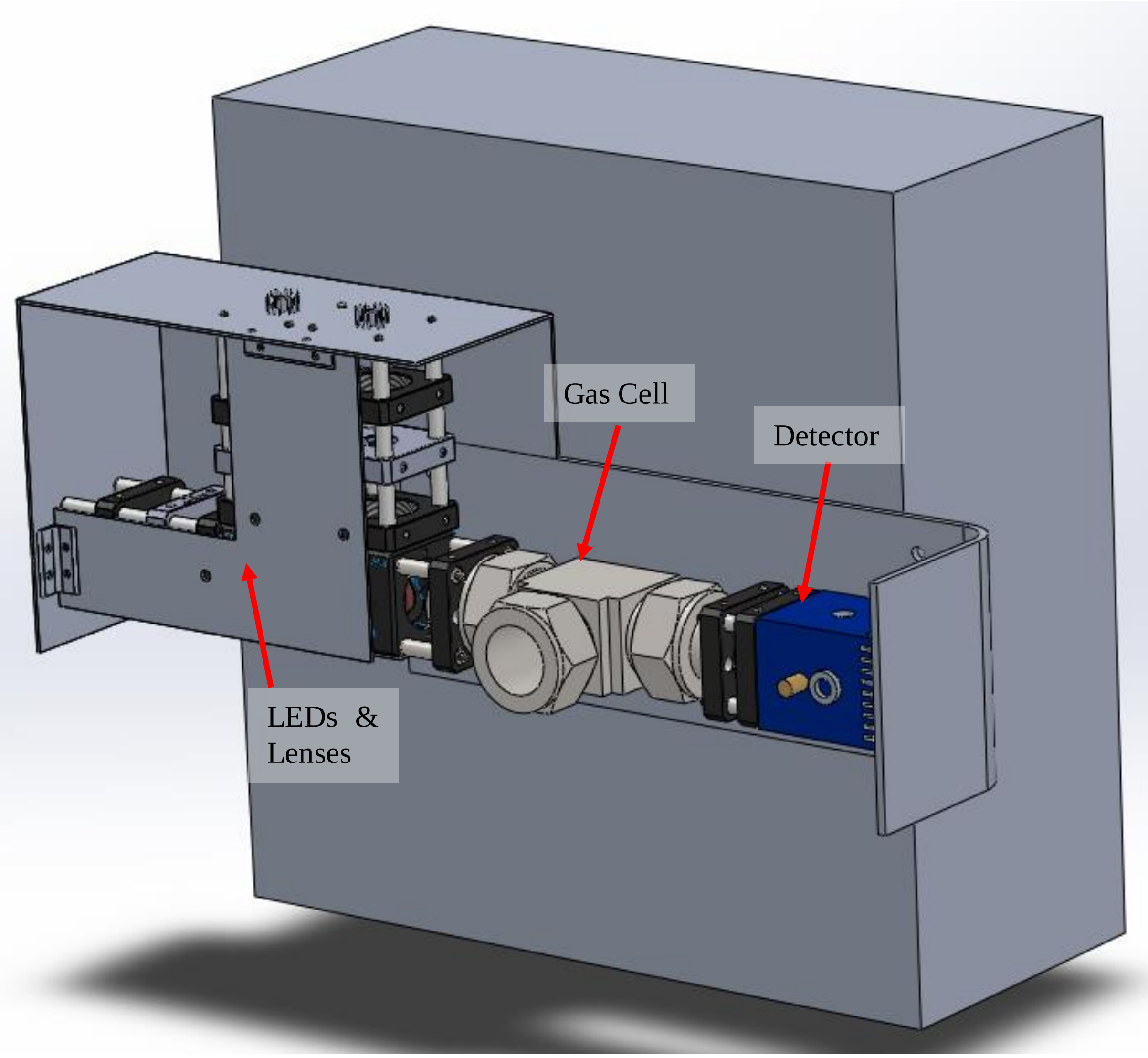

Figure 4: The University of Central Florida payload consists of a 12x12x5in. aluminum box with the test apparatus externally mounted.

The mass and power budget is broken down below in table 4. Most of the mass taken up by the structure and DAQ however the payload is still well below the 20kg limit. Power demands come almost entirely from the DAQ however payload is still within the limits for utilizing the HASP's onboard power supply. If we find that the power requirements are beyond the HASP's limits we may choose to supply the payload with its own battery power given the ample mass capacity. The NI DAQ requires a 9 to 30VDC input while all other components have a maximum voltage requirement of ~12VDC therefore the voltage will have to stepped down to 12VDC.

Table 4: Mass and power budget.

Component	Mass (g)	Mass Uncertainty (g)	Power (W)	Power Uncertainty (W)
LED + TEC x3	30	3	1	0.1
Detector + TEC	100	5	1	0.1
Optics	100	20	-	-
Structure	5260	1000	-	-
DAQ	2400	200	40	2
Driving Electronics	110	15	12	5
Total	8000	1243	54	7.2

4. Preliminary Drawings

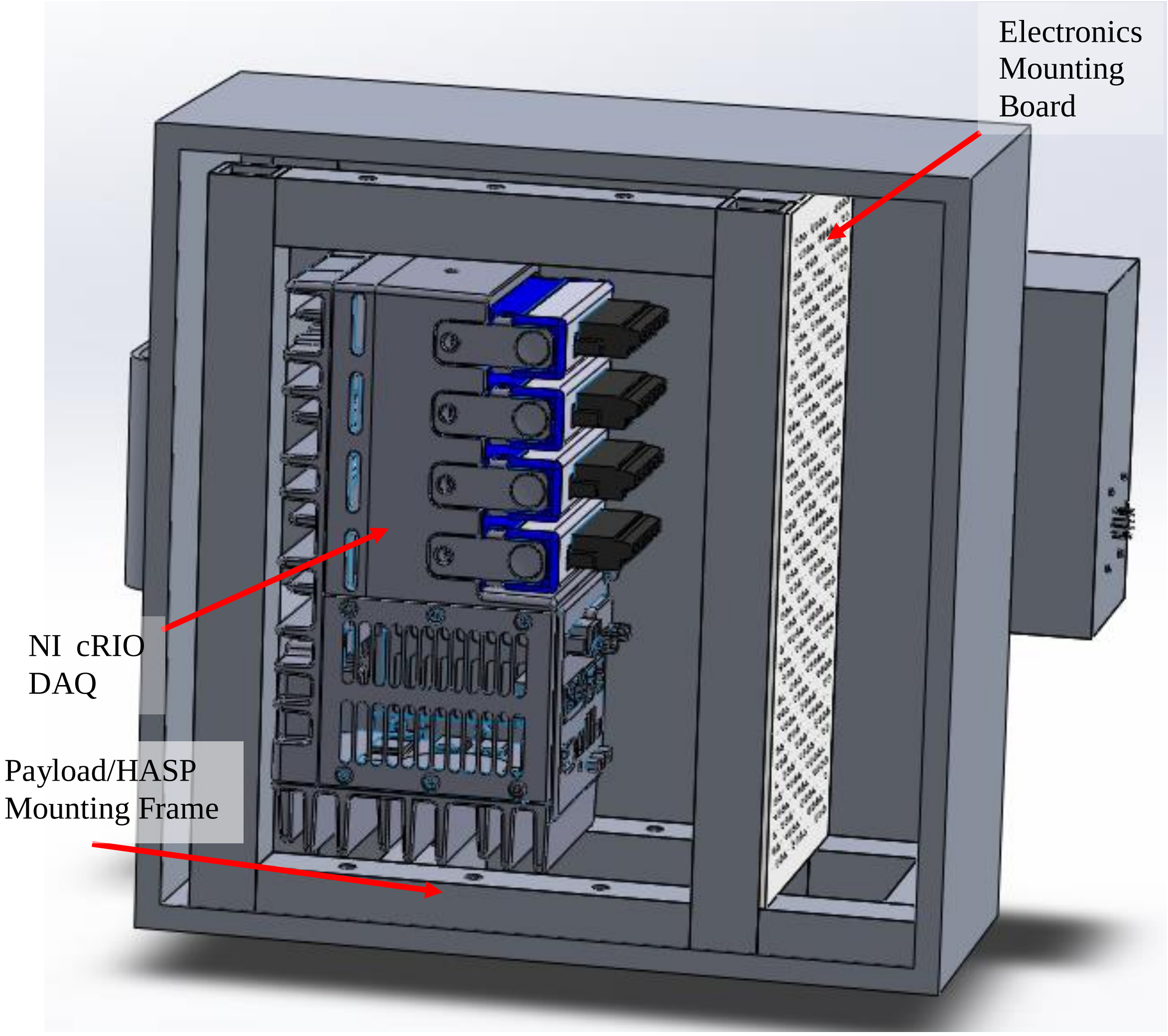

Figure 5: Payload with access panel removed. The EDAC 516-020 connector will be accessed from the right panel.

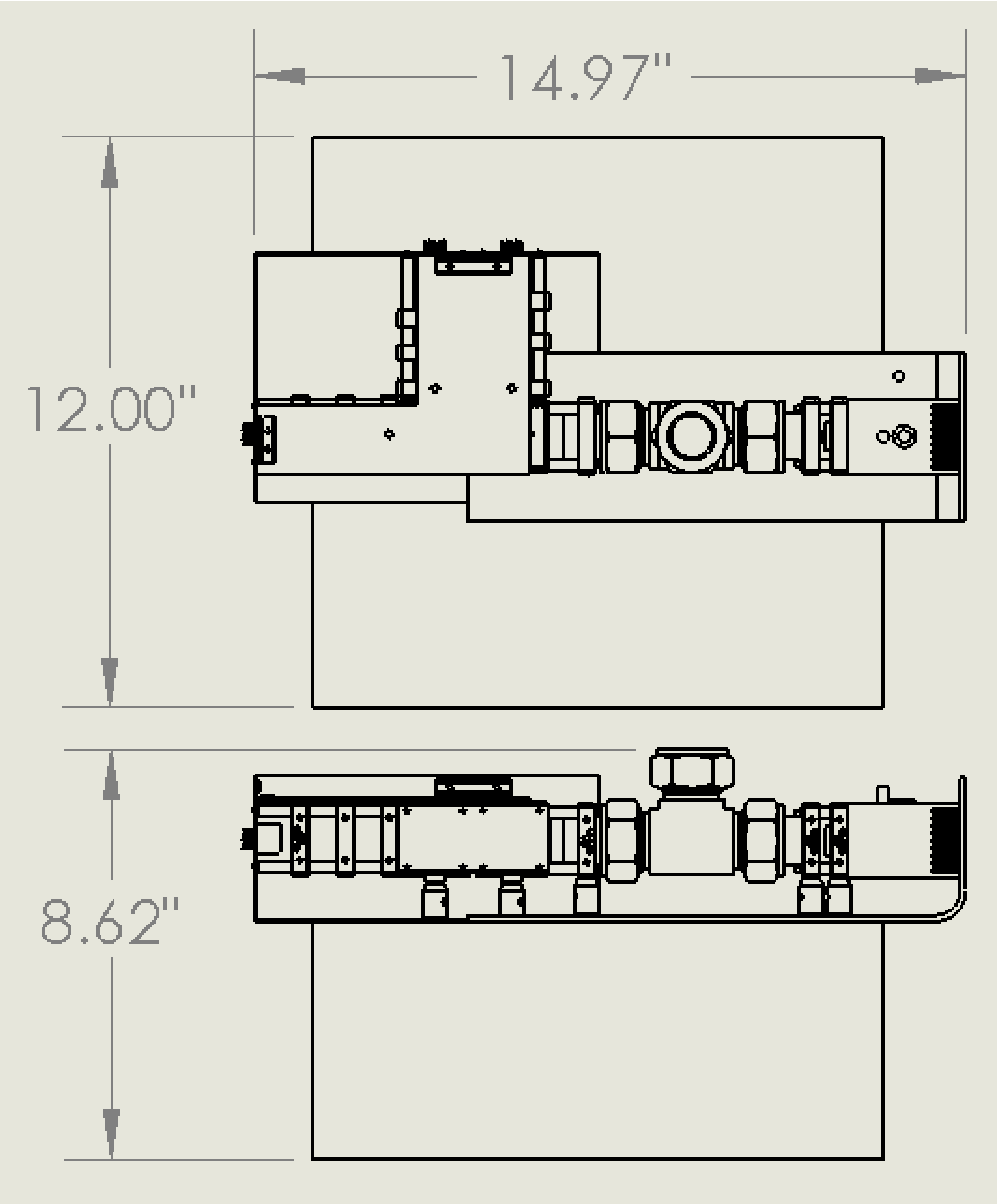

Figure 6: Mechanical drawing and external dimensions of payload.

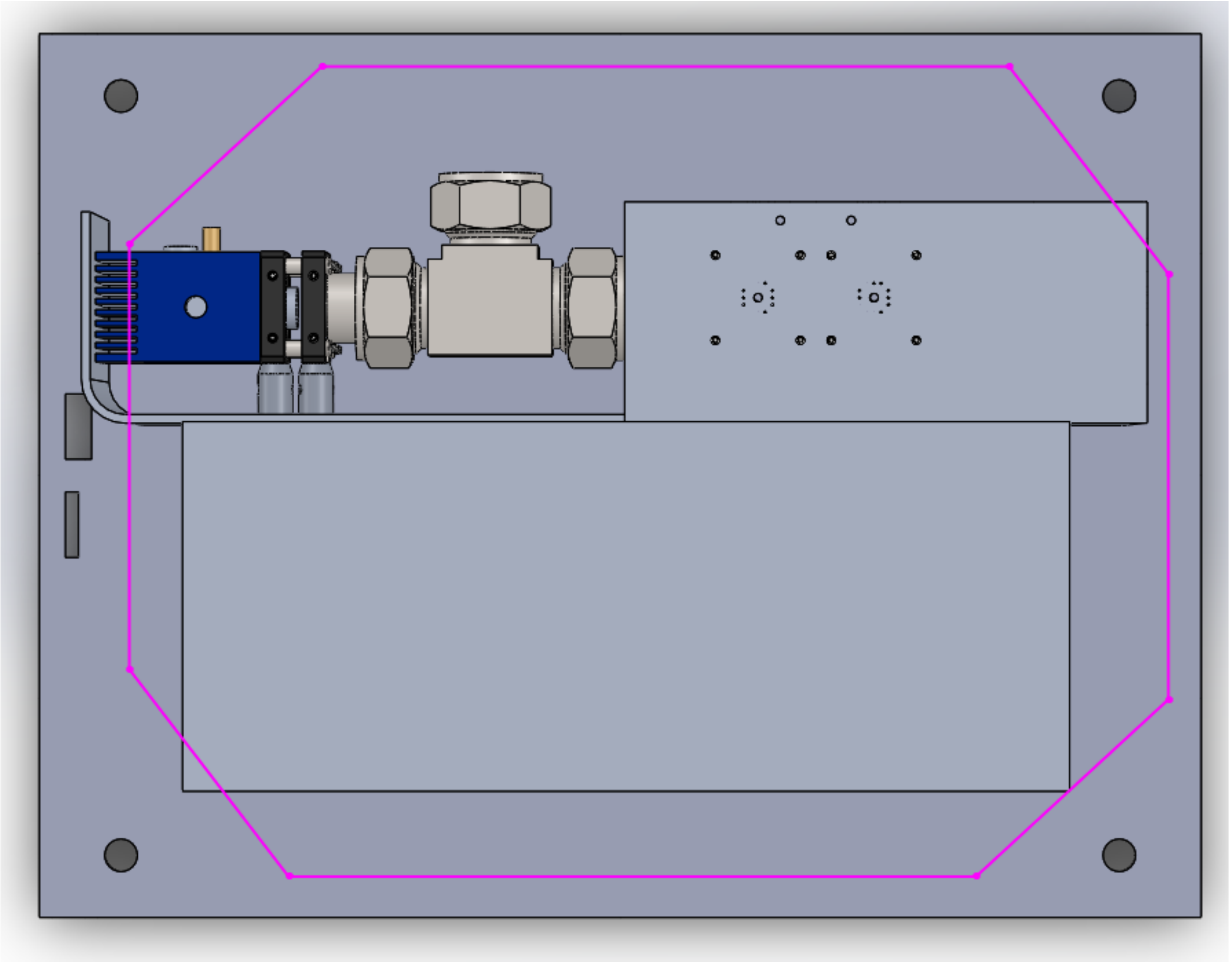

Figure 7: The current payload design overhangs the keep out area slightly however if this presents as a problem we are confident we can work the design by flight time to reduce the size in these areas to fit within the mounting area completely.

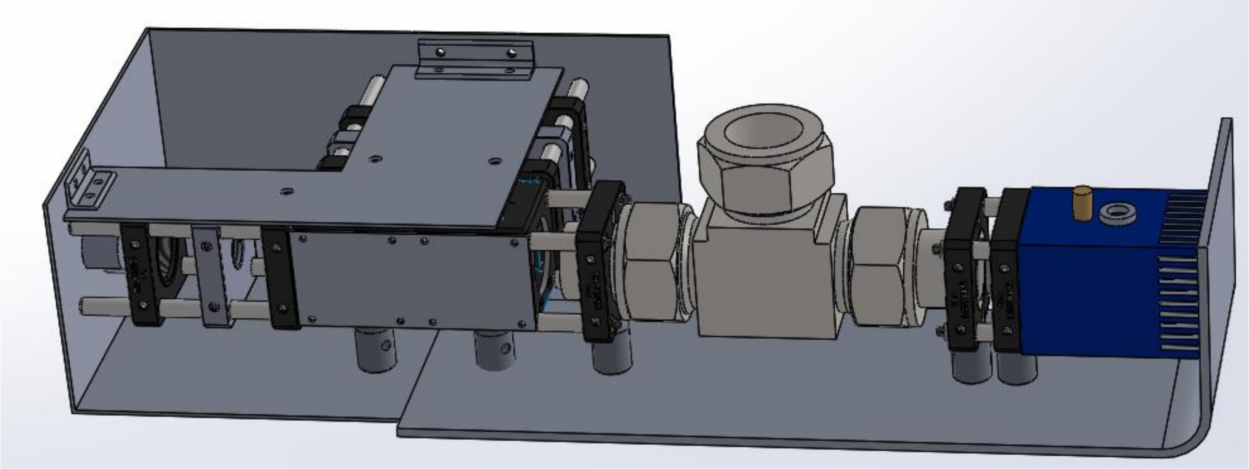

Figure 8: The unit under investigation, the LED CO/CO2 sensor. Fromleft to right: the LEDs and collimating optics, the gas cell, the photovoltaic detector.

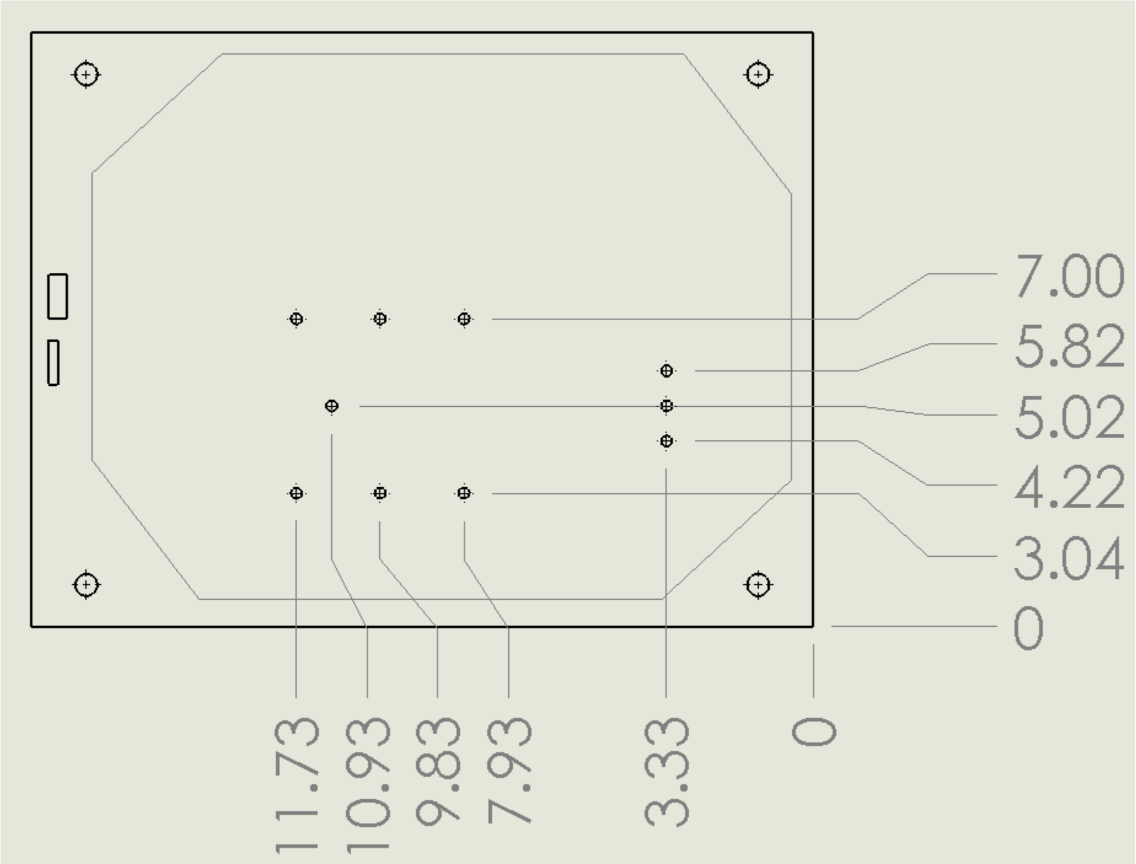

Figure 9: The current payload design would require the following hole pattern to be drilled into the HASP interface. Dimensions in inches.

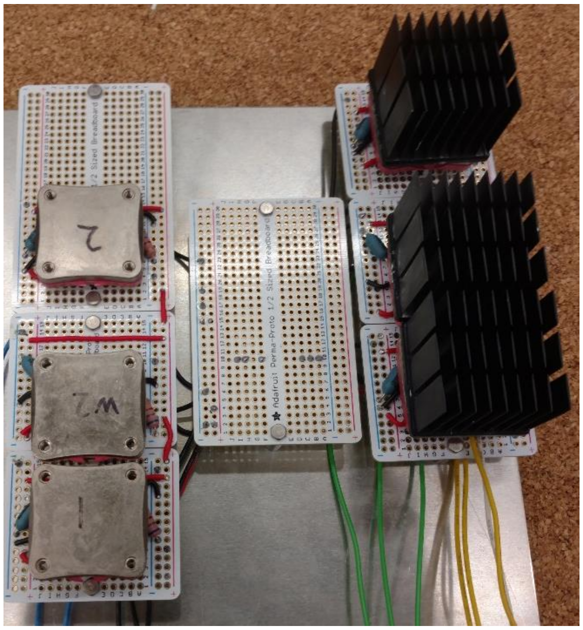

Figure 10: Driving electronics that are used to power LEDs and TECs. The modules are Wavelength Electronics WLD3343general purpose drivers. Additional circuitry would have to be developed to regulate the power fed to these boards and the NI DAQ which require ~12VDC

References

[1] Ruff, G. A., 2003, "Research Needs in Fire Safety for the Human Exploration and Utilization of Space."

[2] Rothman, L., Gordon, I., Babikov, Y., Barbe, A., Benner, D. C., and Bernath, P., 2013, "The HITRAN database: 2012 edition," J Quant Spectrosc Radiat Transfer.

[3] Thurmond, K., Loparo, Z., Partridge Jr., W., Vasu, V., 2016, "A Light-Emitting-Diode (LED) Based Absorption Sensor for Simultaneous Detection of Carbon Monoxide & Carbon Dioxide," Applied Spectroscopy.