

HASP2013 Proposal

Development of a free flying payload to measure the ozone profile in the stratosphere using improved nanocrystalline sensor arrays on a high altitude balloon platform

Submitted by



University of North Dakota (UND)

and



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(1) Project Summary

The UND-UNF team has successfully flown payloads on the HASP balloon flights since 2008 and measured the ozone gas profile in the stratosphere. The measured ozone profiles matched very well with the expected theoretical profile. Based on the success, particularly last 2012 flight with the few known scientific and technical problems of these payloads, the UND-UNF team proposal for the HASP 2013 flight is for the development of a free flying payload to verify the generation of ozone and to measure the ozone profile using an improved version of the gas sensor arrays and radio payload. The output of the proposed payload will help us with the development of a free flying payload consisting of small gas sensors capable of flying on meteorological weather balloon, rockets, or sub-orbital space vehicles. This payload will include improved versions of the 8 Nanocrystalline ITO thin film gas sensors, 8 Nanocomposite WO₃-ITO thin film gas sensors, 6 Nano-fibers ITO thin film gas sensors, as well as 2 commercially available ozone sensors that will be used to verify the performance of the sensors. The temperature controller will be used to control operating temperature of all gas sensors. Three sensors boxes will be mounted on the three sides of rectangular payload body. An ultra violet light sensor will be mounted just below ozone gas sensors box in order to measure the amount of photo voltage generated by UV light, which will support the science concept of ozone gas generation in the presence of UV light. This concept will help us to understand the effect of any dark shadows on the gas sensors, particularly at the time of sunset, as well as provide information on how ozone gas concentrations decrease during the night. In addition, a temperature sensor will measure the ambient temperature, improved pressure sensors for measure high and low pressure ranges, and an improved GPS which can measure altitude throughout the flight without any blockage of transmission will be mounted on the payload. Payload data communication will be performed by the HASP communication link as well as the government certified radio, antenna and battery pack. The radio can be turned on or off by command from the ground. Ozone sensors will be fabricated and calibrated with ozone gas in low pressure chamber at UNF and also tested at UND. The gas sensors and other transducers will then be integrated with the electronics circuit and software to complete the payload. The developed sensor payload will meet all of the HASP requirements such as weight, size, power, communication, and thermal vacuum test for the balloon flight. The software will allow us to convert RAW files directly into one EXCEL file. Furthermore, the surface topography of the sensors before and after the flight will be studied using a scanning electron microscope, and the chemical composition of the surface of the sensors will be analyzed by energy dispersive analysis of x-rays at UNF. Both the North Dakota and Florida Space Grant Consortia may support this student project.

(2) Significance of Project

ITO-QCM (Quartz Crystal Microbalance) sensor technology (Patented) and nanocrystalline gas sensor arrays technology (Patent Pending) are being developed by Dr. Patel at the University of North Florida (UNF) for the detection of toxic gases, explosive materials and chemical warfare agents with support of the Edgewood Chemical Biological Center, US Army lab, and the U.S. Department of Defense. Nanocrystalline gas sensors have also been used for the detection of ozone gas in the stratosphere. Nanocrystalline indium tin oxide (ITO) gas sensors were

successfully tested and calibrated with ozone gas at the Kennedy Space Center (KSC) and at the University of North Dakota (UND) during 2008-2009. The UNF team is continuously improving the performance of ozone sensors by changing its fabrication conditions and modifying its surface structure. These sensors were successfully tested on HASP flights from 2008 to 2012. These sensors also used by the students of Louisiana State University and University of Central Florida for their weather balloon projects.

The proposed development and fabrication of different types of gas sensors payloads have several unique features. ITO gas sensor arrays have higher sensitivity and stability because of the nanocrystalline thin film structure. Earlier reported work on tungsten oxide sensors for the detection of ozone gas (Hansford *et al.*, 2005) required a high operating temperature of about 450°C to detect ozone, while the UNF developed nanocrystalline ITO sensor arrays operate at ambient temperatures and do not require a heater. This ultimately saves power and space, while also minimizing the possibility of an accidental fire. The UNF developed nanocrystalline nanocomposite WO₃+ITO and ZnO +ITO gas sensors have high stability under harsh upper atmospheric conditions. The UNF developed gas sensor arrays are very small in size, have low weight, and low power consumption that meets the payload requirements for space applications. These gas sensors can also easily be integrated with microcontroller electronic circuits. Compared to more conventional costly spectroscopic and other reference methods for the detection of ozone, our payload of gas sensor arrays provides low cost and low weight for the rapid detection of gases in the stratosphere.

(3) Work Plan

The proposed work is a continuation of UND-UNF joint efforts made during the last five years. Brief information about the output of last five HASP flights is summarized in Fig.1. The flight picture and measured ozone profiles are shown in Fig. 2.

HASP Flight Year	Ozone profile measured by gas sensors	Technical Issues	Conversion of RAW data files	No of students involved	
				UND	UNF
2008	Yes	Payload body was not user friendly	Mostly by manually	4	2
2009	Yes	Voltage regulator and capacitor	Mostly by manually	3	3
2010	Yes	Temperature of sensors raised during evening time	By software	3	3
2011	Yes	GPS failed after 60,000 ft. and saturation of pressure sensor below 100 mbar	By software	2	4
2012	Yes	GPS failed after 60,000 ft. and saturation of pressure sensor below 100 mbar	By software	2	2

Fig.1 Overview of previous flights

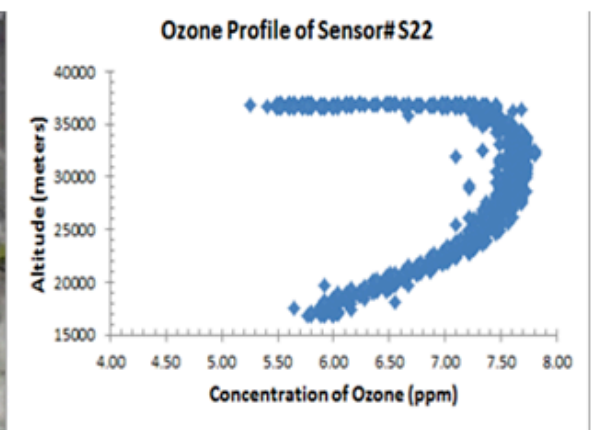
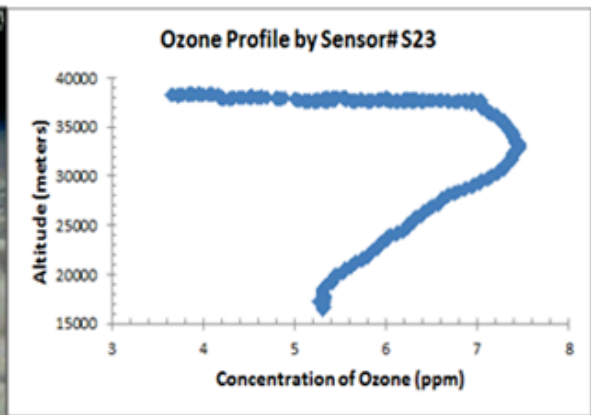
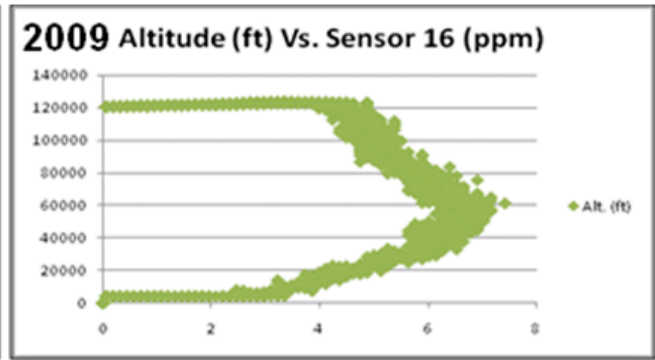
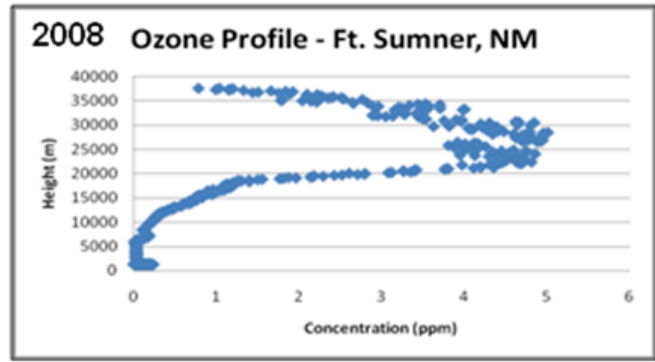


Fig. 2 UND-UNF payload on HASP 2008, 2009, 2010 and 2011 balloon flights with measured ozone profiles

Work Plan for the Proposed Science Experiment

Based on the success and few known scientific and technical problems with the HASP balloon flights from 2008 to 2012, the UND-UNF team proposes a HASP 2013 flight with following new objectives for ozone profile measurement in the stratosphere using improved versions of the gas sensor arrays and radio payload.

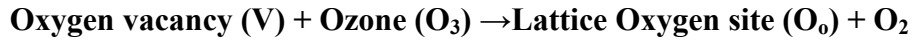
- (i) To develop low weight payload which can work as a free flying payload and can be easily integrated with meteorological weather balloons, rockets, and sub orbital space vehicles for measurement of gas profiles in the upper layers of the atmosphere.
- (ii) Improved versions of 8 Nanocrystalline ITO thin film gas sensors, 8 Nanocomposite WO₃-ITO thin film gas sensors, 6 Nano-fibers ITO thin film gas sensors, along with 2 commercially available ozone sensors which will be used to verify the performance of the ozone sensors. Improved gas sensors will have better sensitivity, selectivity, stability and faster response and recovery times. UNF students will fabricate ITO thin film gas sensors using the electron beam deposition method. The commercially available ozone sensors may be purchased from www.e2v.com and other firms. Three sensors boxes will be mounted on the three sides of rectangular payload body.
- (iii) All 24 gas sensors will be calibrated simultaneously in the low pressure chamber in order to minimize the experimental error for the trendline equations of the plots for converting resistance values into concentration of ozone in part per million (ppm). The pressure and temperature inside the test chamber will be maintained at the same levels as in the stratosphere. Ozone sensors will be tested at UND for the cross verification.
- (iv) A sensor array box consisting of 8 gas sensors, 1 flexible heater, 1 temperature sensor and 1 mini fan will be mounted on the side of the payload body. A total of three sensors boxes will be mounted on the three available sides of cubic payload body. Gas molecules can enter in the sensor box through perforated holes in the payload body. Fan will protect the surface of sensor by blowing away dust particles in the atmosphere and ice particles in the troposphere. Temperature of ozone gas sensors will be maintained nearly constant in the range of 25 to 30 °C using an on-off temperature controller. Flexible heater (MINCO make) and temperature sensor (Analog Device TMP 36) will be mounted on the back side of gas sensors.
- (v) An ultra violet (UV) light sensor will be mounted just below the gas sensor array box on each side of the payload body. The light sensor will support the science concept of generation of ozone in the presence of UV light. The amount of photo voltage generated and measured by the UV light sensor will indicate how much of UV light is available to interact with oxygen to create ozone gas in the vicinity of the ozone gas sensors. Nanocrystalline ITO thin film gas sensors will detect and measure the concentration of that generated ozone gas. This concept will also help us to understand the effect of any shadow or darkness on the surface of the sensors, particularly at the time of sunset and how much the ozone concentration decreases at night time.
- (vi) A temperature sensor (TMP 36) will be mounted on the outer surface of payload to monitor any change in the outside ambient temperature with altitude and time.

- (vii) It was observed that the pressure sensor used in the last two flights worked well from atmosphere to 100 mbar and then saturate. We propose to use two pressure sensors: one will measure from atmosphere to 100 mbar and second will measure below 100 mbar to monitor the pressure in the stratosphere.
- (viii) It was found that the GPS used in the last two flights was not functioning over an altitude of 60,000 feet. The transmission was blocked or jammed due to governmental regulations. We proposed to use an improved and Government certified GPS to measure the altitude of the balloon flight. The measure altitude using GPS will be cross verified and compared with the HASP GPS data.
- (ix) The new addition to the payload will be used at 900 MHz or higher radio frequency for communication of data. We propose to communicate our data using the HASP communication link as well as the payload radio. Government certified radio in the payload may be turned on or off by command from the ground. Radio circuit will have antenna and may operated by battery backup or HASP power. We aim to test our communications technology in order to help us build a free flying payload for future flights.
- (x) A single hollow aluminum tube structure will be used to make the payload body. The body work will be almost same as the last flight. This design will reduce the numbers of screws and nuts and, therefore, weight of the payload. This will also allow us to easily open and close the payload for access to the hardware. There will no outgassing at low pressure.
- (xi) Thermal blanket may be applied on the payload for the improvement of thermal stability.
- (xii) UNF sensors will be integrated with the UNF electronics circuit and software to complete the payload. Both teams will jointly analyze the data after the flight. The software will allow us to convert all RAW files directly into one EXCEL file. Then, calibration trendline equations will be applied to convert the change in resistance values of sensors into the concentration of ozone gas in ppm.
- (xiii) The surface topography of the sensors before and after the flight will be studied using a scanning electron microscope, and the chemical composition of the surface of the sensors will be analyzed by energy dispersive analysis of x-rays at UNF.
- (xiv) The developed payload will eventually work as **a free flying payload** for rapid detection of ozone or any other gas in the real time mode and will be able to be integrated into weather balloons or rocket payloads for space and environmental applications.

Working Principle of Gas Sensors

Interaction of ozone gas on surface of n-type ITO thin film gas sensor

Upon adsorption of charge accepting molecules at the vacancy sites from oxidizing ozone (O₃) gas, electrons are effectively depleted from the conduction band of ITO. Vacancies can be filled by reacting with ozone. Filled vacancies are effectively electron traps and as a consequence, the resistance of the sensor increases upon reacting with ozone.



Fabrication of Gas Sensor Arrays

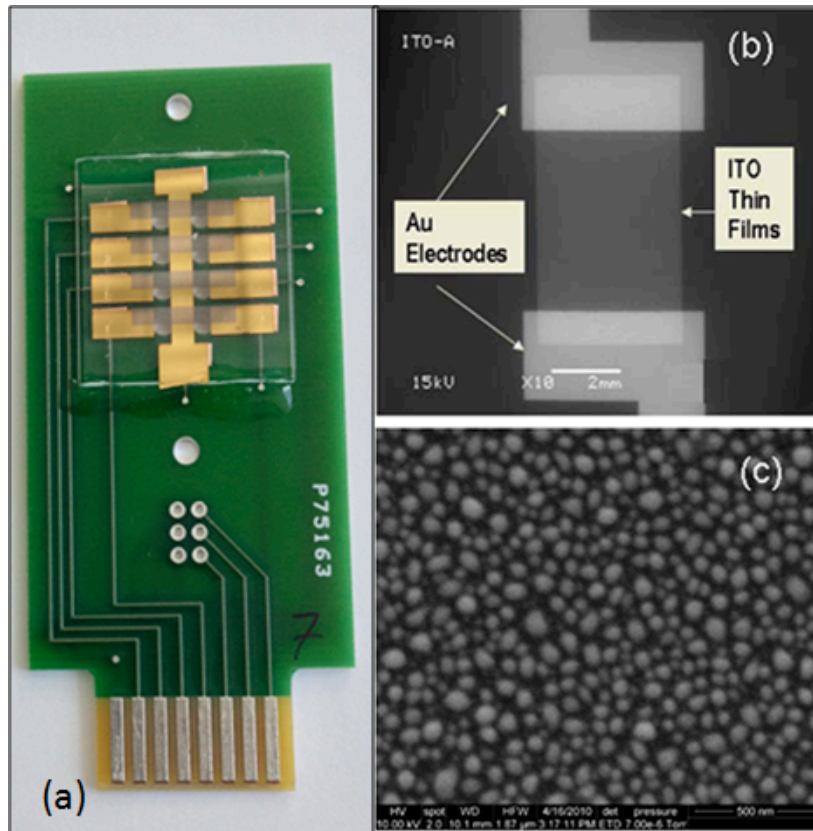


Fig.3 (a) 8 sensor array and interface mini PCB, scanning electron micrograph of (b) top view of one ITO gas sensor and (c) nanocrystalline grains of ITO thin film

Nanocrystalline ITO thin film gas sensors array (UNF patent pending) will be fabricated over the ultrasonically and chemically cleaned glass substrates. Fig. 3(a) shows the top view of 8 sensor array and the interface printed circuit board. Fig. 3(b) shows a scanning electron micrograph of one ITO thin film gas sensor having two gold electrodes for external electrical contacts. Fig.3(c) shows a scanning electron micrograph of nanocrystalline gains of the ITO thin film.

Three different types of gas sensor array boxes will be fabricated at UNF. Each box will have 8 gas sensors, one heater, one temperature sensor and one fan (Fig. 4).

Box#1: 8 improved version of nanocrystalline ITO thin film gas sensors

Box#2: 8 improved version of nanocomposite WO₃-ITO thin film gas sensors

Box#3: 6 Nano-fiber ITO thin film gas sensors and 2 commercially ozone sensors

Each type of sensor array box will have different sensor characteristic parameters for the detection of ozone gas.

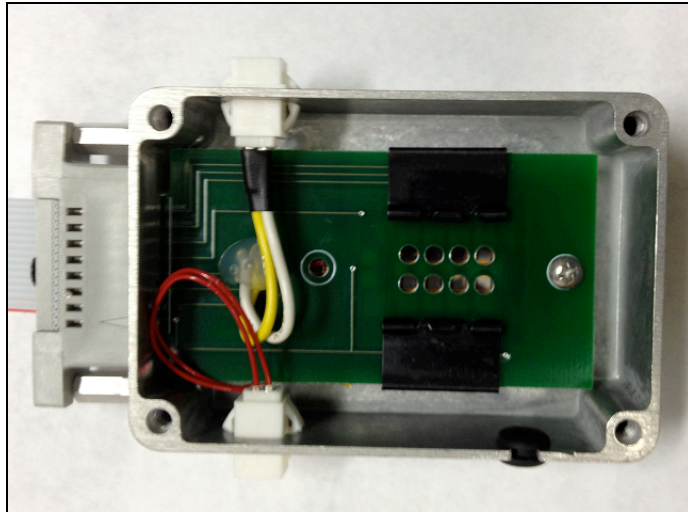


Fig. 4 Schematic diagram of sensor array box

The sensor array will be interfaced with the printed circuit board and its 16-pin female card edge connector and flat cable. Sensors will be tested and calibrated with ozone under low pressure at UNF. An ozone generator (Ozone Solutions, Model# OMZ-3400) will be used as the source of ozone, which generates 0 to 12 ppm ozone gas. A digital ozone detector (Eco Sensors, Inc., Model:A-21ZX) will be used to measure the concentration of ozone. Keithley electrometer and multimeter with LabView software will be used to measure resistance of all sensors simultaneously in the test chamber. The parameters of trendline equations of calibration plots will be used for the determination of concentration of ozone. The surface morphology of the gas sensors and CSTFTs before and after recovery of the payload will be examined using a scanning electron microscope (SEM) at UNF. The chemical composition of the sensors will be determined using Energy Dispersive Analysis of X-rays (EDAX) at UNF in order to check for any possible damage and contamination on the surface of the sensors occurred during the flight.

Fabrication of payload

A miniature, flexible, and low power heater (MINCO make) will be integrated on to the backside of the sensor arrays. The purpose of the heater is to combat the low temperatures of the troposphere and keep the sensors at a nearly constant temperature in the range of 25 to 30°C. A miniature temperature sensor (TMP 36) will also be mounted to monitor and control the temperature of the sensors using a closed loop control electronics circuit. The sensors array with a printed circuit board will be mounted in a low weight aluminum box. Three boxes will be mounted on the three sides of the low weight payload body. Outer temperature sensor and GPS antenna will be mounted on the top plate of the payload. The wall of the payload will be covered by a thermal blanket. A miniature low power fan will be mounted on the front of the sensor box to push gas molecules over the surface of the sensors. The fan will mainly work during the upward and downward journey of the flight. The fan may stop rotating during float in the stratosphere because of the low pressure. A wire mesh will be fixed over the fan in order to filter out dust particles and protect the surface of the sensors. The sensor box containing the sensors, fan, heater, and temperature sensor will be interfaced with the microcontroller circuit and payload.

UND and UNF Team Structure

The team structures, distribution of work and management methods will remain largely the same as last year with inclusion few new students. Fig.5 shows the chart for the team management

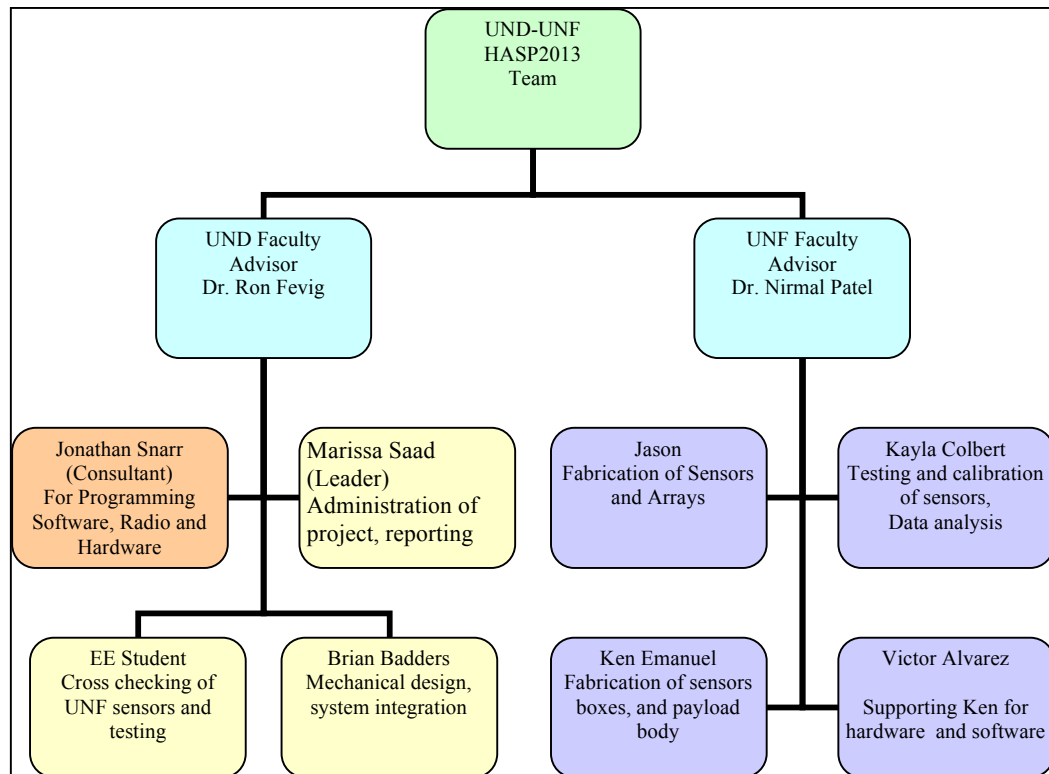


Fig.5 Team Management

UND-

- (1) Marissa Saad (Student Leader) is a space studies graduate research student with a degree in Astronomy. She will take care of the organization of meeting and teleconference meeting with all members and faculty advisors, and communicating with the HASP. She will take the lead for the integration and thermal vacuum testing of the payload at Palestine, TX and pre-flight testing at Fort Sumner, NM. She will also be responsible for the flight operation plan, monthly reports, work updates, and any issue concerning both advisors.
- (2) Jonathan Snarr (Consultant) was a student leader of the HASP 2010 and 2011 flights and a consultant for the 2012 flight. He developed the new version of the microcontroller circuits, GPS, and software for the payload. He will continue to help the UND-UNF team with electronic circuits, hardware and software. He will provide all previous versions of software and hardware for the 2013 team. He will be responsible for assisting all the members of the team.

- (3) Brian Badders is a space studies graduate student with a mechanical and aerospace engineering background. He will focus on the mechanical structure and system integration.
- (4) One EE student will help with the software work as well as the HASP communication line with the payload.
- (5) Additional, yet unidentified members will be added to the effort as needed.

UNF –

- (1) Jason Saredy is a graduate physics/biology student and was an active participant in the last five HASP efforts. He will be useful for the fabrication of the array of gas sensors.
- (2) Kayla Colbert is an undergraduate physics student. She will be responsible for testing and calibrating the sensors. She will also perform the report and post-flight data analysis work.
- (3) Ken Emanuel is an undergraduate mechanical engineering student and was an active participant for HASP 2012 efforts. He will design and fabricate sensor array boxes and payload body. He will integrate the sensors with the flexible heater, temperature sensor and fan into the metal box. He will also integrate the payload body and mount the sensors in the payload.
- (4) Victor Alvarez is an undergraduate computer science student. He will work with the UND team for software work and also support Ken for hardware work.

Task and Work Plan Path

The initial work breakdown structure (WBS) includes the basic tasks required of the HASP project. This includes the Proposal, Integration Plan, Integration Certification, Operation Plan, and Science Report. Because we also intend to fly an identical payload through the local High Altitude Balloon group at the University of North Dakota (UND), this task includes the creation of an identical bus to that of HASP. This way, all anomalies can be detected in a true flight mode. The work plan path is given in Fig.6.

2013	UND	UNF
January	Conceptual Design Review (CoDR) for sensors, electronic circuits, software and payload. Reviewing issues of HASP2008 to 2012 flights.	
February	Preliminary Design Review (PDR) for sensors, electronic circuits, software, payload, integration of payload with HASP and data analysis.	
March	Critical Design Review (CDR) for sensors, electronic circuits, software, payload, integration of payload with HASP and data analysis.	
April	Designing of circuit board and programming.	Fabrication and testing of sensor arrays, designing of payload body
May	Fabrication of circuit board and programming, modifications, if any	Calibration of sensors and delivery of sensor arrays to UND for testing
June	Testing of radio, circuit and sensor	Fabrication of sensors box and payload body.

	arrays. Integrating the circuits and the sensor arrays	Reviewing HASP flights, data and any issues.
July	Integration of circuit board and sensor box with the payload body. Development of protocols for communication of payload with HASP computer and RAW files to EXCEL file	Integration of sensor arrays in box. Integration of sensor boxes with payload body. Integration of PCB to payload and sensors box
August	Flight operation plan, Testing payload, thermal vacuum test of payload and integration of payload with HASP platform	
September	Pre-flight testing of payload, launching of payload and downloading data files, and data analysis work	
October	Payload recovery, testing of sensor arrays and other components, SEM+EDAX analysis of sensor arrays and shorting of issues and failure analysis. Data analysis.	
November	Data analysis and report writing	
December	Submission of the science report and then enjoying holidays.	

Fig. 6 Work plan path

HASP Integration

It is expected that a minimum of three students and one faculty member from UND and UNF will travel to CSBF, Palestine, Texas, in the first week of August (as per the date given by HASP) for payload integration. It is also expected that approximately four students and two faculty members from UND and UNF will travel to Ft. Sumner for the launch of the HASP 2013 payload during September 2013 (as per the date given by HASP and CSBF).

Payload

The operation of the sensors and ozone gas measurements are processed according to the improved version of the payload block diagram (shown in Fig. 7). Resistance values from the ozone gas and pressure sensors are converted to voltages by the conditioning circuitry. Resistance values from the ozone gas and pressure sensor are converted to voltages by the conditioning circuitry. These analog values are converted to digital values by a microcontroller that interfaces with the HASP data handling system. Temperature, light, and pressure sensor readings are processed in a similar manner and are folded into the data stream by the microcontroller. Power from HASP is conditioned by circuitry based on voltage regulators and is provided to each payload electrical subsystem.

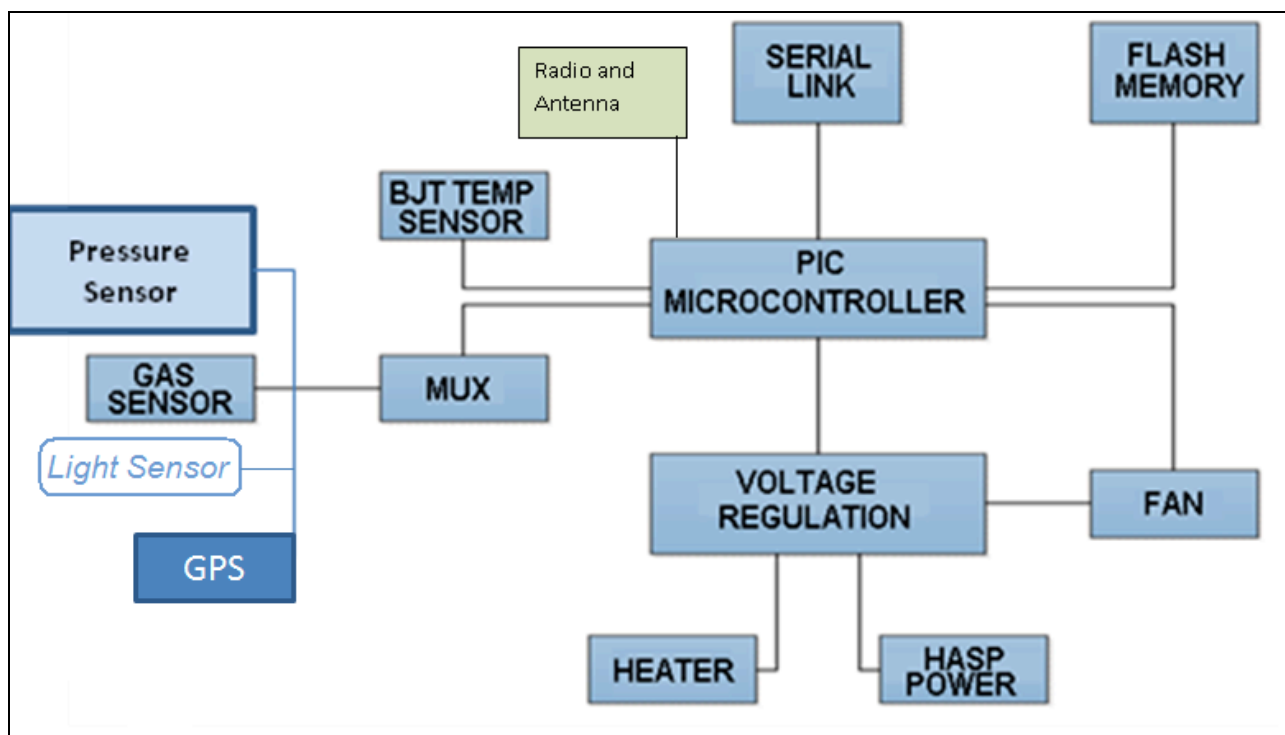


Fig.7 Block diagram of electronic circuits

Mounting Footprint

The mounting plate design we will use is provided in the HASP Student Payload Interface Manual (Version 02.17.09) and is shown below in Fig.8. This mounting plate design will not require modification.

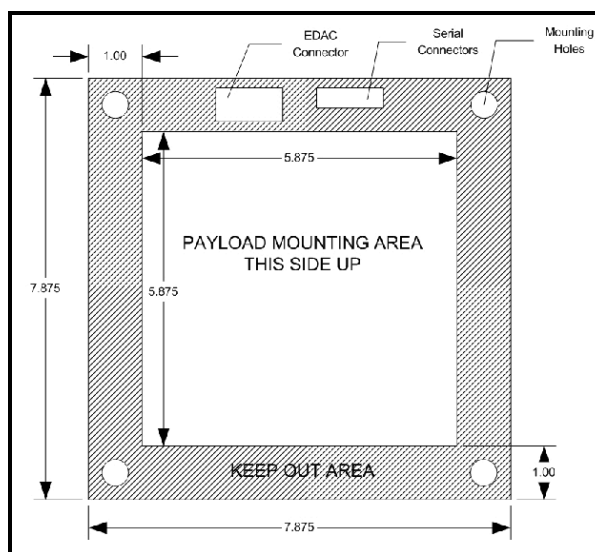


Fig. 8 Mounting Plate for small payload (Courtesy: HASP Version 02.17.09)
http://laspace.lsu.edu/hasp/documents/public/HASP_Interface_Manual_v21709.pdf

Desired Location and Orientation

The requested smaller payload should be oriented on the side farthest away from any solar cells, so they will avoid disparate solar thermal radiation. There should not be any obstacles limiting air circulation into the payload. Also, it should not be subjected to shadows created by other payloads. We also prefer that CosmoCam camera should be able to view our payload, particularly at nighttime to watch the blinking LEDs for the data collection. We would like the position of the payload (#7) on HASP to be the same as in the previous 2008 to 2012 flights. We hope that position #7 should not have any issues with power supply. Fig. 9 shows our desired location of payload on HASP.

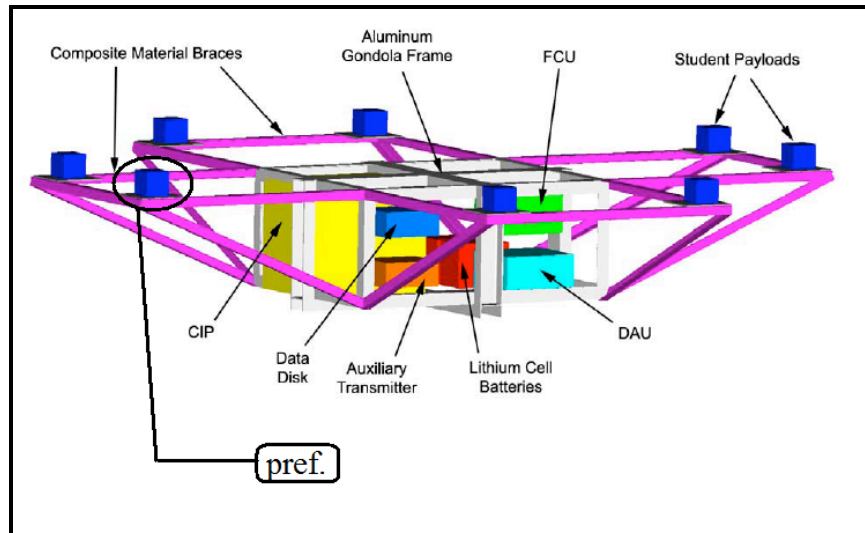


Fig. 9 Proposed HASP Configuration (Guzik and Wefel, 2004)

Payload Dimension

The proposed payload is under the category of small payload. The height of payload will be within 30 cm and sides will be within 15 cm x 15 cm. Payload mass will be within 3.00 kg.

Payload Mass Budget

The weight budget is itemized below in Table 1.

Table 1 – Itemized Mass Budget

Item:	Mass:
Sensor array boxes (including fan, heater, box)	300g
Electronic circuits board	300g
Payload body and top plate	1200g
Cables and any other items	200g
Total	2200g

The expected mass of payload will be about 2.20 kg, without the HASP mounting plate. This is quite less than the 3.0 kg small payload limit. We will continue to try to lower the total weight.

Payload Power Budget

The 0.5 Amps at 30 VDC power supplied by HASP adequately accommodates the power requirements for the payload electronics, as well as the heater and fan for the sensor. Table 2 details the preliminary estimate for our power budget

Table 2 – Itemized Power Budget

Item:	Power requirement:
Payload Electronics	1 W
Sensor Heater	7 W (max.)
Sensor Fan	2 W
Total	10 W

This is less than the 15 W limits for the smaller payloads.

Preliminary heat transfer calculations (shown in Equation 1) show the onboard sensor heater is adequate to keep the sensor at nominal conditions. We are exploring the effects temperature has on the component's integrity. This research is ongoing and part of our investigation. These initial estimations take the proposed materials for the walls into consideration. A minimum temperature of -60°C and a general operating temperature of 15°C are considered (From altitude variation of 0 km to 36 km shown in the modified Fig. 10, altitude profile).

Equation 1 – Heat Transfer

$$q = m(\Delta T)C_p$$

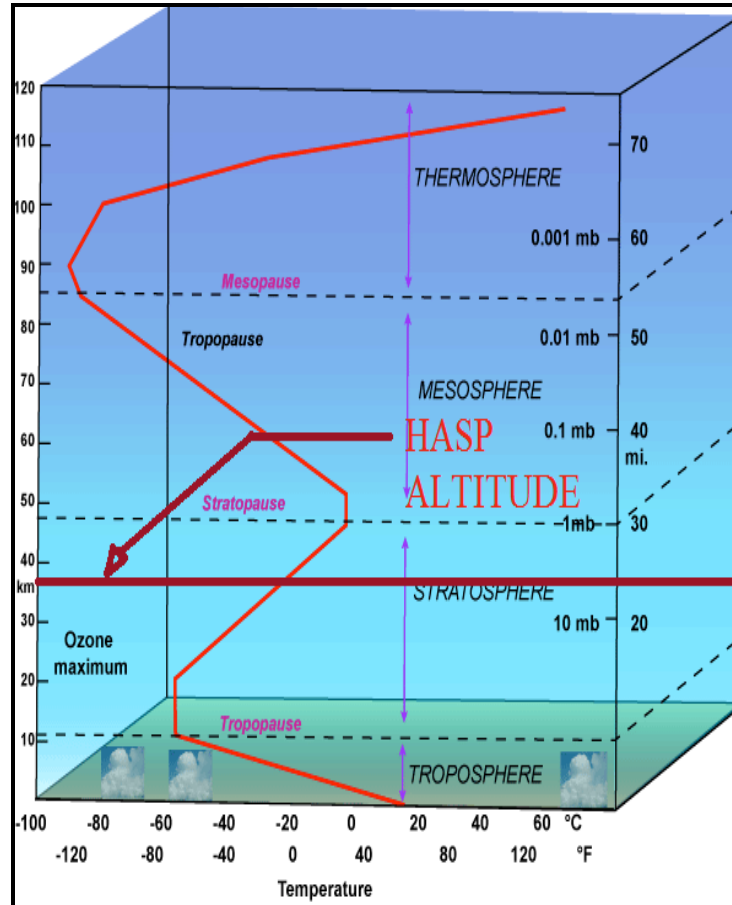


Fig. 10 – Modified Altitude Profile (Atkins, 2007)

As per the instructions, on the EDAC 516 power connector only pins A, B, C, and D are wired to the payload as +30 VDC power supply. Pins W, T, U, and X are wired to the payload for grounding in order to avoid failure of the power circuit or loss of payload functionality. A voltage regulator is not necessary according to initial tests despite the slightly higher +33 VDC at launch for the sensor; however, a voltage regulator and divider will be used for peripherals. Fig. 11 shows the EDAC516 receptacle pin layout.

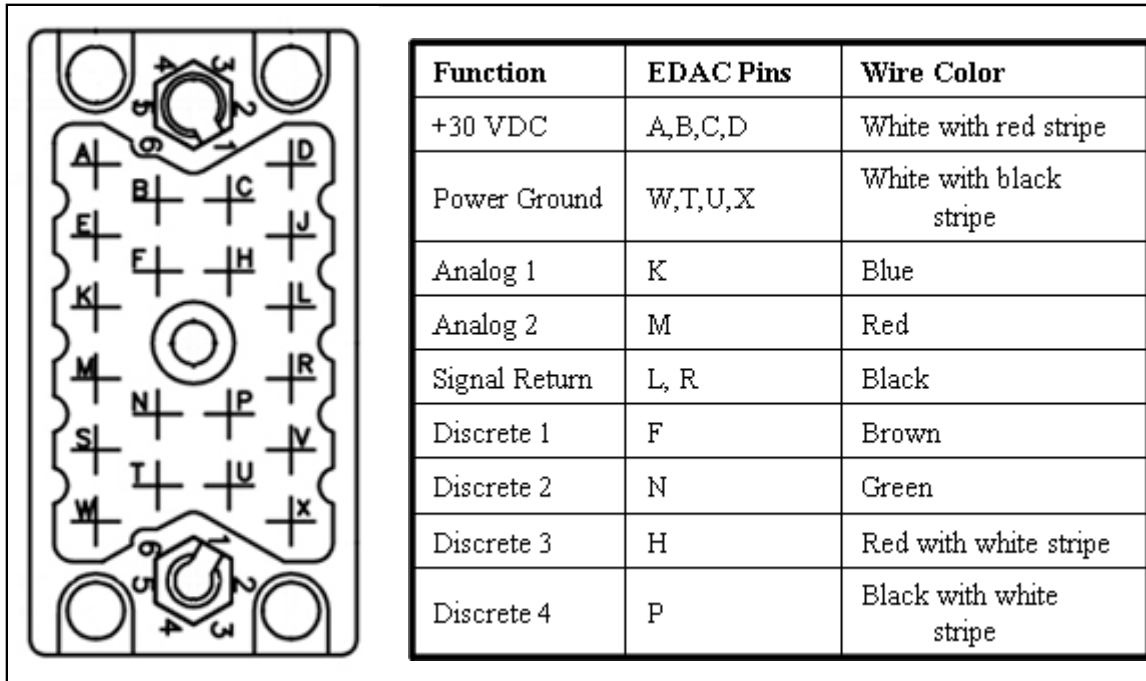


Fig. 11 EDAC516 receptacle pin layout (Courtesy: HASP manual).

Downlink Serial Telemetry Rate

The payload module requires the RS232 HASP telemetry to send the state of resistance to the ground. A data-recording unit will be included with a master controller in the event that the telemetry link fails. The DB9 needs to be connected to the HASP system's telemetry system so that the data can be sent to the base station (via the RS232 link). The RS232 link will operate at 2400-baud, with the standard RS232 protocol with eight data bits, no parity, one stop bit, and no flow control. A standard packet will contain the information-formatted vis-à-vis the Student Payload Serial Connection section of the HASP-Student Interface Document. Fig. 12 shows DB9 pin diagram.

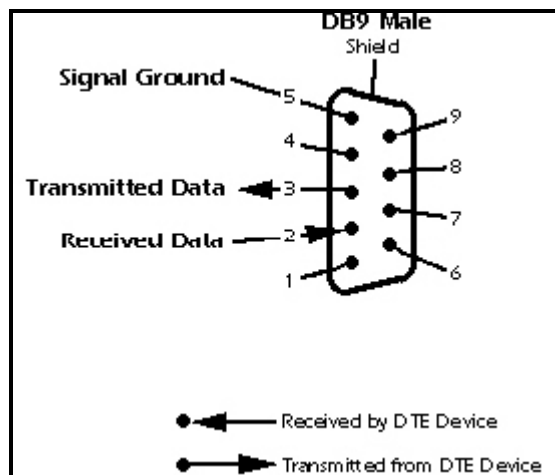


Fig. 12 DB9 pin diagram (courtesy: HASP manual)

Uplink Serial Command Rate

No uplink commands are anticipated.

Anticipated Use of analog downlinks

No additional analog downlinks are anticipated.

Payload

There will be no hazardous chemicals, gases, or biological samples in the payload.

Anticipated Additional Discrete Commands

No additional active discrete commands are anticipated.

Anticipated Procedures

Prior to Integration:

- Testing and Calibration of sensor arrays
- Set initial values for data recorder
- Place sensor arrays in appropriate payload slots
- Check program and LED for status

Integration:

- Mount payload module to HASP
- Connect HASP Power Connector
- Connect HASP Serial Connection
- Test system by recording initial readings and making sure all data is nominal
- Troubleshoot

Pre-Flight Operations and testing:

- Set initial values for data recorder
- Place sensors in appropriate payload slots
- Check all batteries
- Connect HASP Power Connector
- Connect HASP Serial Connection
- Check mass and size of payload
- Test thermal-low temperature and high temperature test
- Test pressure and vacuum test
- Test 10g vertical and 3g horizontal vibration/impact test

Flight Operations:

- Record values for resistance across the sensors

Post-Flight Operations:

- Examine all parts of payload

- Remove PCB and sensor array boxes from the payload. Test PCB with power and test sensor boxes
- Send sensor array boxes to UNF for electrical testing, SEM+EDAX analysis, and failure analysis.

Financial Considerations

UND will seek funding through North Dakota Space Grant Consortium. UNF will request Florida Space Grant Consortium for the funding for the students support, travel and consumables.

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