HASP Student Payload Application for 2010

Payload Title: **Measurement of the ozone profile in the stratosphere using nanocrystalline and nanocomposite sensor arrays on a high altitude balloon platform**.		
Payload Class: (circle one) Small Large	Institution: University of North Dakota (UND) and University of North Florida (UNF)	Submit Date: 12-18-2009

Project Abstract: The UND and UNF team have successfully flown payloads on both the HASP 2008 and 2009 balloon flights for the purpose of measuring the ozone gas profile in the stratosphere. The nanocrystalline ITO thin film gas sensor array developed by UNF was used for the detection of the ozone gas profile, while the signal conditioning and microcontroller circuits developed by the UND team were used in the ozone sensor payload. Based on the success and the few known problems of these payloads, the UND-UNF team proposes a HASP 2010 flight for the verification of earlier data using improved versions of the sensors and payload. Three different groups of ozone sensor arrays: (i) nanocrystalline ITO sensors, (ii) nanocomposite organic-ITO gas sensors on glass substrates and (iii) nanocomposite inorganic-ITO gas sensors on glass substrates will be used for the comparison of sensitivity, speed of response and stability of the sensors. Recently, the UNF team invented nanocomposite ITO gas sensor arrays, which show better sensitivity than that of ITO sensors on glass. Both groups of ITO sensors for ozone will operate at temperature about 30 ^{o}C and need no high temperature heater, unlike other metal oxide sensors, which may conserve electrical power. In addition, several bugs in the electronics circuits and software of the last year's payload will be corrected. An improved version of the payload will be integrated and tested by the ***"Cross-Check and Verification"*** approach. First, UNF sensors will be calibrated with ozone gas at UNF, and then at UND labs for cross verification. Then, UNF sensors will be integrated into the UND electronics package to complete the payload. Finally, the completed payload will be tested first at UND and then at UNF. Both teams will jointly analyze the data after the flight. 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. This student project continues through the Dakota Space Society student organization, with support from both the North Dakota and Florida Space Grant Consortia.

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HASP2010 Proposal

Measurement of the ozone profile in the stratosphere using nanocrystalline and nanocomposite sensor arrays on a high altitude balloon platform

Submitted by
University of North Dakota (UND)
and
University of North Florida (UNF)

Students Team:
Shannon Negaard (Interim Leader) and others (UND),
Nathan Walker, Bernadette Quijano, Jason Saredy and Ryan Shore (UNF)

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PREVIOUS WORK AND ACKNOWLEDGEMENT

<u>HASP 2008</u>

The University of North Dakota (UND) and the University of North Florida (UNF) team made a joint effort to measure the ozone gas profile in the stratosphere through HASP 2008. A nanocrystalline ITO thin film gas sensors array developed by UNF was used for the detection of the ozone gas profile, while the signal conditioning and microcontroller circuits developed by the UND team were used in the ozone sensor's payload. UNF sensor arrays (patent pending) were developed and fabricated at UNF with support of the Edgewood Chemical Biological Center, US Army lab, and the U.S. Department of Defense. The payload was launched by on a HASP balloon flight for 32 hours. The payload worked successfully to measure the profile of ozone. The payload and data were recovered. Post-flight analysis of the payload noted very little change to the functionality of the sensors' response. The measured ozone profile was nearly matched with the expected theoretical, but the maximum magnitude of measured value of ozone was smaller by a few ppm than that of the expected value because of the effect of hurricane Ike during the flight period. Some of the pictures and figures of HASP2008 work are highlighted in Fig. 1. One thesis for master degree and one research paper presented at an international conference and published in the proceedings of the conference (Ambler *et al* 2008) were the major outputs of the HASP2008 work.

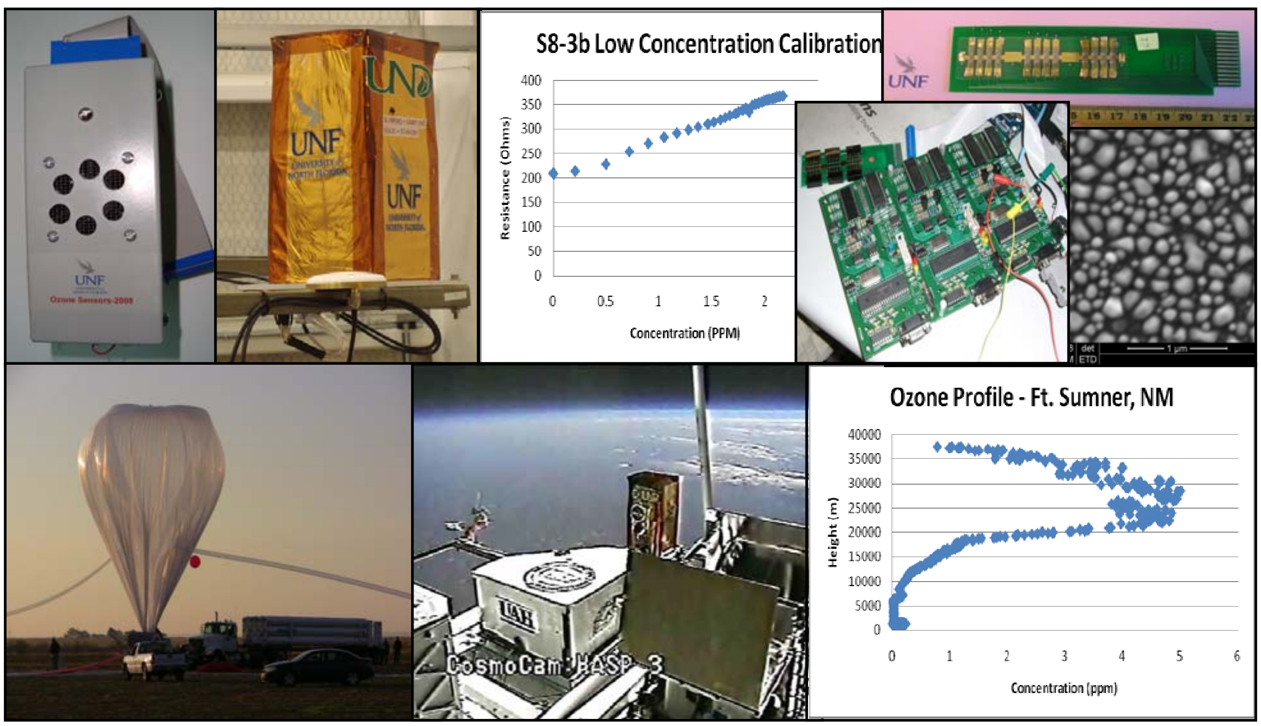

Fig. 1 Images of HASP2008 work

<u>HASP 2009</u>

Based on this fruitful experimental work, the UND-UNF team participated in the HASP2009 flight to reconfirm the earlier obtained data using three different groups of sensor arrays. During the first thermal vacuum test, a few electronic components were failed and were replaced. One voltage regulator for the group-3 sensor array failed after the second thermal vacuum test and was not replaced. The payload was certified to fly with two groups of sensor arrays. All 15 sensors, except two, measured the ozone profile very well during the balloon flight during the ascent. The measured profiles were matched with the expected theoretical profile. Some of pictures and figures of HASP2009 work are highlighted in Fig. 2. One thesis for honor degree and one research paper are under preparation out of the HASP2009 work.

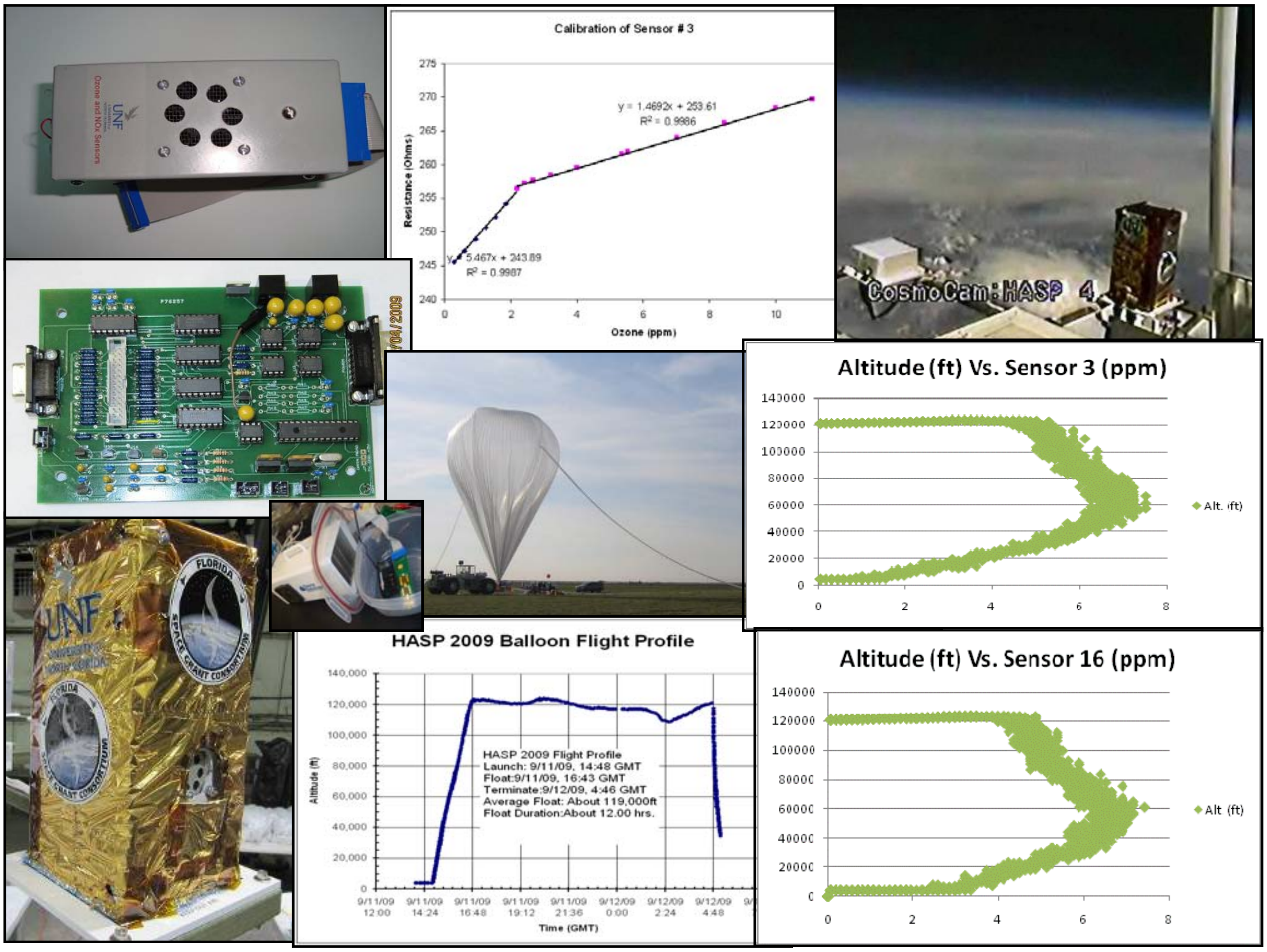

Fig. 2 Images of HASP2009 work

Work plan for HASP 2010

Based on the success and the few known problems of these payloads, the UND-UNF team proposes a HASP 2010 flight for the verification of earlier data using improved versions of the sensors and payload. Three different groups of ozone sensor arrays: (i) nanocrystalline ITO sensors, (ii) nanocomposite organic-ITO and (iii) nanocomposite inorganic-ITO gas sensors on glass substrates will be used for the comparison of sensitivity, speed of response and stability of the sensors. Recently, the UNF team invented nanocomposite organic-ITO gas sensor arrays, which show better sensitivity than that of ITO sensors on glass. Nanocomposite inorganic -ITO gas sensor work is in progress. The US Army, Edgewood Chemical and Biological Center, and APG have been funding the UNF sensors group over the last three years. The earlier reported tungsten oxide sensors for the detection of ozone gases (Hansford *et al.*, 2005) required higher operating temperature of about 450^{o}C to detect ozone, whilst the UNF developed nanocrystalline ITO sensors arrays operate at 30^{o}C temperature and requires no high temperature heater. This limited requirement ultimately helps reduce both the payload power consumption and payload volume. In addition, several bugs in the electronic circuits and the software systems of the last year's payload will be corrected. An improved version of the payload will be integrated and tested by the ***"Cross-Check and Verification"*** approach. First, UNF sensors will be calibrated with ozone gas at UNF, and then at UND labs for cross verification. Then, UNF sensors will be integrated into the UND electronics package to complete the payload. Finally, the completed payload will be tested first at UND and then at UNF. Both teams will jointly analyze the data after the flight. 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. This student project continues through the Dakota Space Society student organization, with support from both the North Dakota and Florida Space Grant Consortia.

STUDENT WORK PLAN

<u>Student Work plan at the UNF</u>

(1) Three different groups of gas sensor arrays will be fabricated at UNF. Each group will consist of 8 nearly identical sensors. All three groups of sensor arrays will be fabricated on 1inch x 3inch ultra cleaned glass substrate and mounted on the interface circuit board as shown in Fig. 3. Group-1: will consist of nanocrystalline Indium tin oxide (ITO) thin film gas sensor array fabricated on the glass substrate. Group-2 will consist of nanocomposite organic-indium tin oxide (ITO) thin film gas sensors array fabricated on the glass substrate. Group-3 will consist of nanocomposite inorganic-Indium tin oxide (ITO) thin film gas sensors array fabricated on the glass substrate. Each group of sensor array will have different characteristic parameters for the detection of ozone gas.

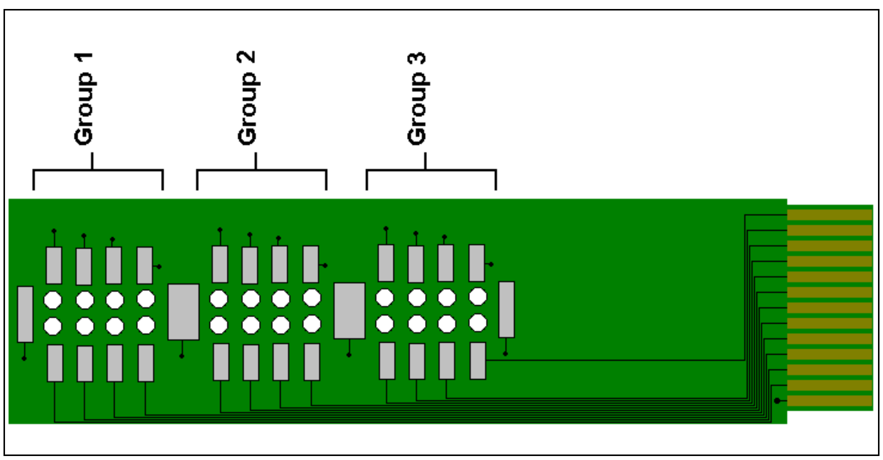

Fig. 3 Schematic diagram of sensor arrays on the printed circuit board

(2) The surface morphology of sensors before and after recovery of the payload will be examined using a Scanning Electron Microscope (SEM), and chemical composition of sensors will be determined using an Energy Dispersive Analysis of X-rays (EDAX) in order to check any possible damages or changes on the surface of sensors.

(3) All sensors will be tested and calibrated with ozone gas at UNF under different temperature and pressure. Trend line equations will be determined from the calibration plots.

(4) The sensors' array will be interfaced with the printed circuit board (patent pending) and its 26-pin connector and cable. A miniature, flexible, and low power heater (Omega or Minco make) will be integrated on the backside of the sensor arrays. The purpose of the heater is to combat the low temperatures at troposphere and to keep sensors at nearly constant temperature around 30^{o}C. A miniature RTD will also be mounted on sensor arrays to monitor and control the temperature using the closed loop electronic circuit. A miniature low power fan will be mounted on the box so that fan can push the gas molecules over the surface of the sensors at the prescribed CFM. A wire mesh will be fixed over the fan in order to filter out dust particles as well as protect the surface of the sensors. Sensors' array with heater and printed circuit board will be mounted in the low weight aluminum box. Three sensor boxes will be fabricated. One will be used for the flight and two will be kept as backup.

(5) The UNF team will also fabricate the body structure of payload on the HASP mounting plate.

(6) Two sensor boxes, a few additional sensor arrays and payload body structure will be delivered to UND team for their testing and cross verification of calibration. After testing, UND team will interface the sensors box with the microcontroller circuit and payload. The payload circuit will be tested as per the guidelines of HASP on the ground before launch.

(7) Electronic printed circuit board and software developed by UND will be cross checked and verified by UNF team

<u>Student Work plan at the UND</u>

(1) Will improve the existing electronic circuits by the following steps:
- Selecting better quality of active and passive components having wider operating temperature range.
- Fabricating of two circuit boards: one for flight and other for backup.
- Modifying the electronic circuits to allow easier integration of components and cables.

(2) UND team will test UNF sensors with ozone gas in the test chamber using an internal generator and a calibrated ozone sensor source for cross verification. Then, UND team will test UNF sensors for compatibility with electronics.

(3) Modify the program for micro-controller. Modify coding and decoding. Adjust the sampling rate with the speed of balloon.

(4) Modify the software for interfacing of payload with HASP payload and data communications.

(5) Simplify the method for converting RAW file into EXCEL file

(6) Perform whatever necessary steps to ensure a safe data recovery from flight, and successful mission.

UND and UNF Team Structure

The team structures and management methods will remain largely the same as the HASP 2009 effort with inclusion of two more faculty advisors and few new students. Fig.4 shows the chart for the team management.

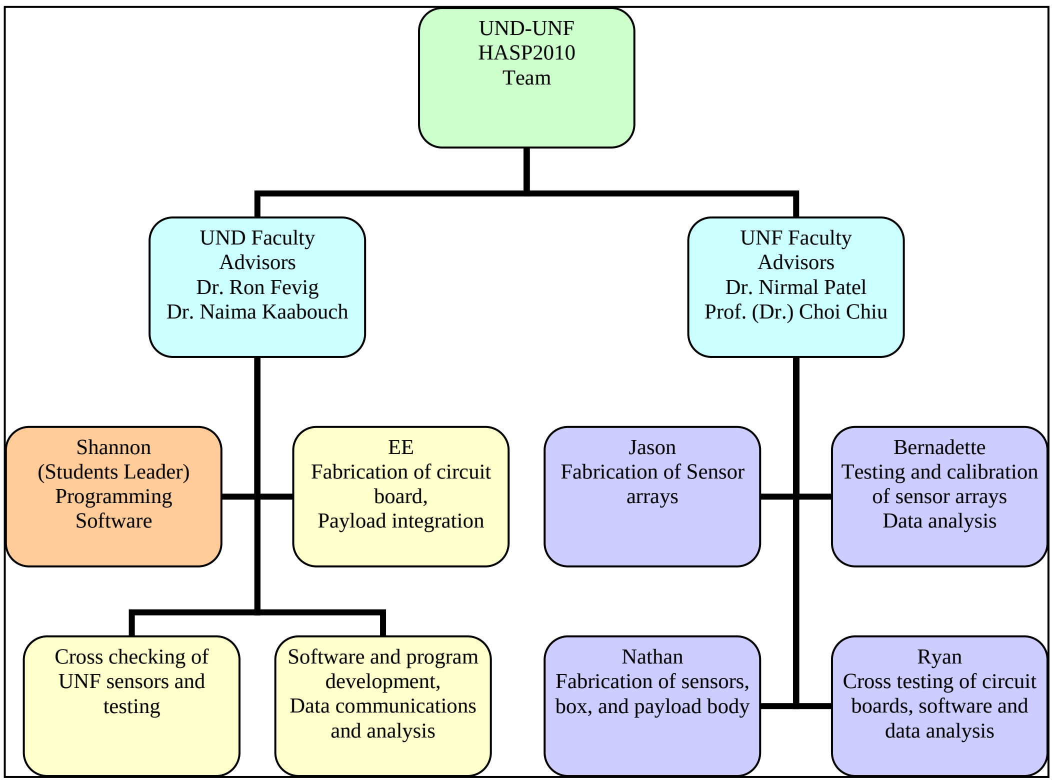

Fig.4 Team Management

UNF –

(1) Jason Saredy is a graduate Physics student and was an active participant in the 2008 and 2009 HASP effort. He will fabricate the gas sensors arrays.

(2) Nathan Walker is an undergraduate electrical engineering student and was an active participant in the 2008 and 2009 HASP effort. He and Jason will fabricate sensor arrays and integrating sensors with flexible heater, RTD and fan in the metal box. He will also fabricate the payload body and mount the sensors box in the payload and help in testing the printed circuit board.

(3) Bernadette Quijano is an undergraduate mechanical engineering student and was an active participant in the 2009 HASP effort. She will be responsible for designing of

payload body, testing and calibrating the sensor arrays with ozone gas under different temperature and pressure and determination of trend line equations. She will also perform the post flight data analysis work and report work.

(4) Ryan Shore is a senior electrical engineering student. He will perform all the cross verification of the electronic and software systems developed by the UND team. He will also make the post flight payload testing, failure analysis and analysis of the payload data.

UND-

(1) Shannon Negaard (Interim Leader) was a student leader of HASP2009 effort and will help establish the necessary framework garnered from the past flight to help support the 2010 HASP UND/UNF effort. This position however, will be filled by a senior student of UND later on. Leader will take care of the organization of meeting and teleconference meeting with all members and faculty advisors, and communicating with HASP. He will take lead for the integration and thermal vacuum testing of payload at Palestine, TX and pre-flight testing at Fort Sumner, NM. He will also responsible for the data analysis work.

(2) One EE student will develop the electronic circuit board and integration of payload with HASP platform.

(3) One EE student will help with the software work as well as the HASP communication line with payload.

(4) One Space Studies student will test the UNF sensor arrays and box. He will also cross-check and verify the calibration of the sensors.

(5) Additional, yet unidentified members will be added to the effort as the needs arise.

Task and Work Plan Path

The initial work break down schedule (WBS) includes the basic tasks required of the HASP project, which includes the Proposal, Integration Plan, Integration Certification, Operation Plan, and Science Report. However, this schedule also includes the strong intent to fly an identical payload locally through the High Altitude Ballooning group at the University of North Dakota (UND), this task includes creating an identical bus to that of HASP so that all anomalies can be detected in a true flight mode. Work plan path is given in Fig.5.

2010	UND	UNF
January	Conceptual Design Review (CoDR) for sensors, electronic circuits, software and payload. Reviewing failure issues of HASP2009.	
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
May	Fabrication of circuit board and programming	Calibration of sensors and delivery of sensor arrays to UND for testing
June	Testing of circuit and sensor arrays. Integrating the circuits and the sensor arrays	Fabrication of sensors box and payload body.
July	Integration of circuit board and sensor box with the payload body. Development of protocols for communication of payload with HASP computer	Testing of UND circuit and program, integration of sensor arrays in box. Delivery of sensor boxes and payload body to UND
August	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.	
November	Data analysis and report writing	
December	Submission of science report	

Fig. 5 Work plan path

HASP Integration

It is expected that a minimum of three students from UND and UNF and one faculty member from UND/UNF will travel to CSBF, Palestine, Texas in first week of August of 2010 (as per the date given by HASP) for the integration of the sensor payload onto HASP. It is also expected that approximately four students from UND and UNF and two faculty members (UND and UNF) will travel to Ft. Sumner for launch of the HASP2010 payload during September 2010 (as per the date given by HASP and CSBF).

Payload Specification

The sensors' operations and ozone gas measurements are processed according to the improved version of electronic circuits given in Fig. 5 to 7. Resistance values from the ozone sensors are converted to voltages by the conditioning circuitry. These analog values are converted to digital values by a microcontroller which interfaces with the HASP data handling system. Temperature sensor and pressure sensor (optional) 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.

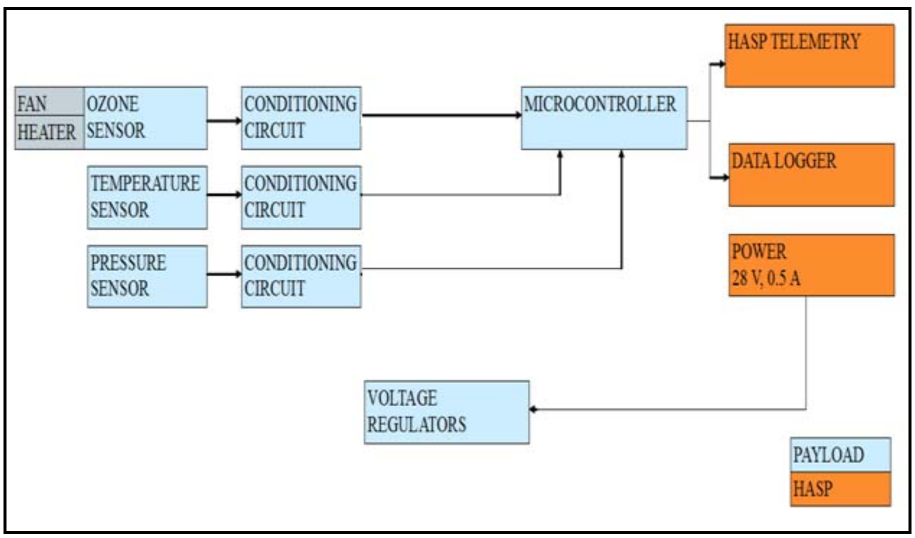

Fig.5 Block diagram of electronic circuit

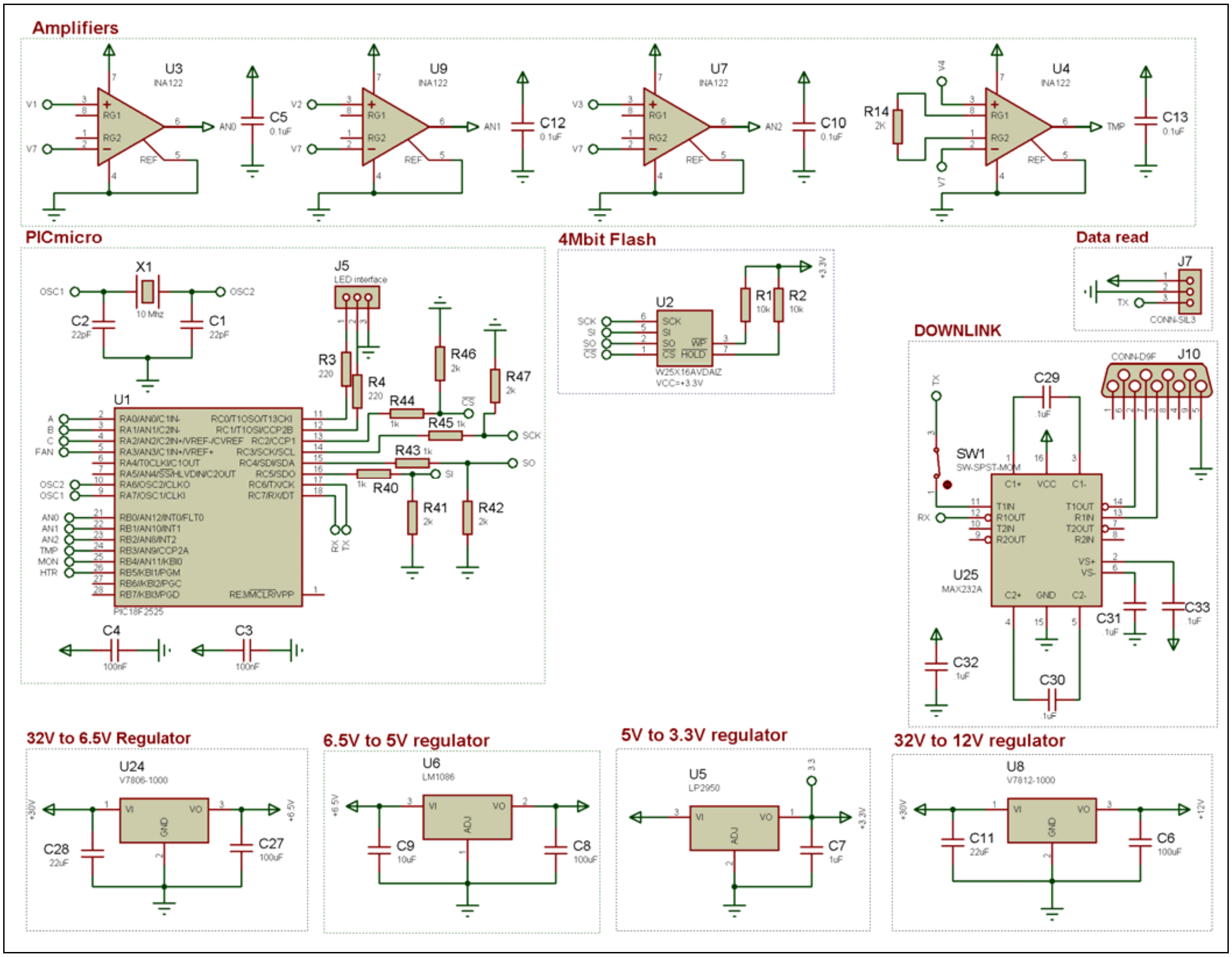

Fig.6 Electronic circuit for amplifier, microcontroller, voltage regulator and downlink

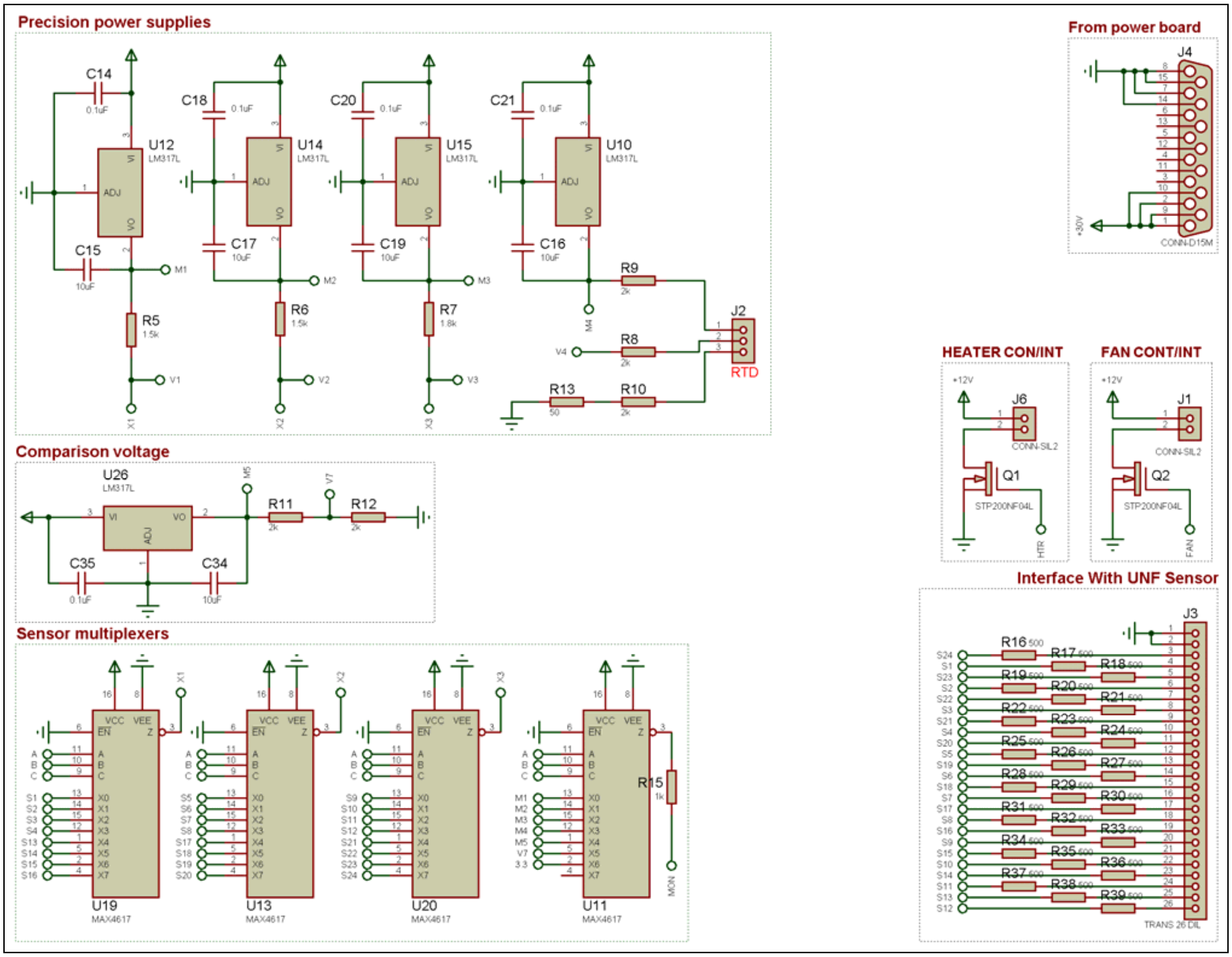

Fig.7 Electronic circuits for multiplexer and power supply

Mounting Footprint

Selection of the small payload dictates the mounting plate that interfaces with the payload. This mounting plate design 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.

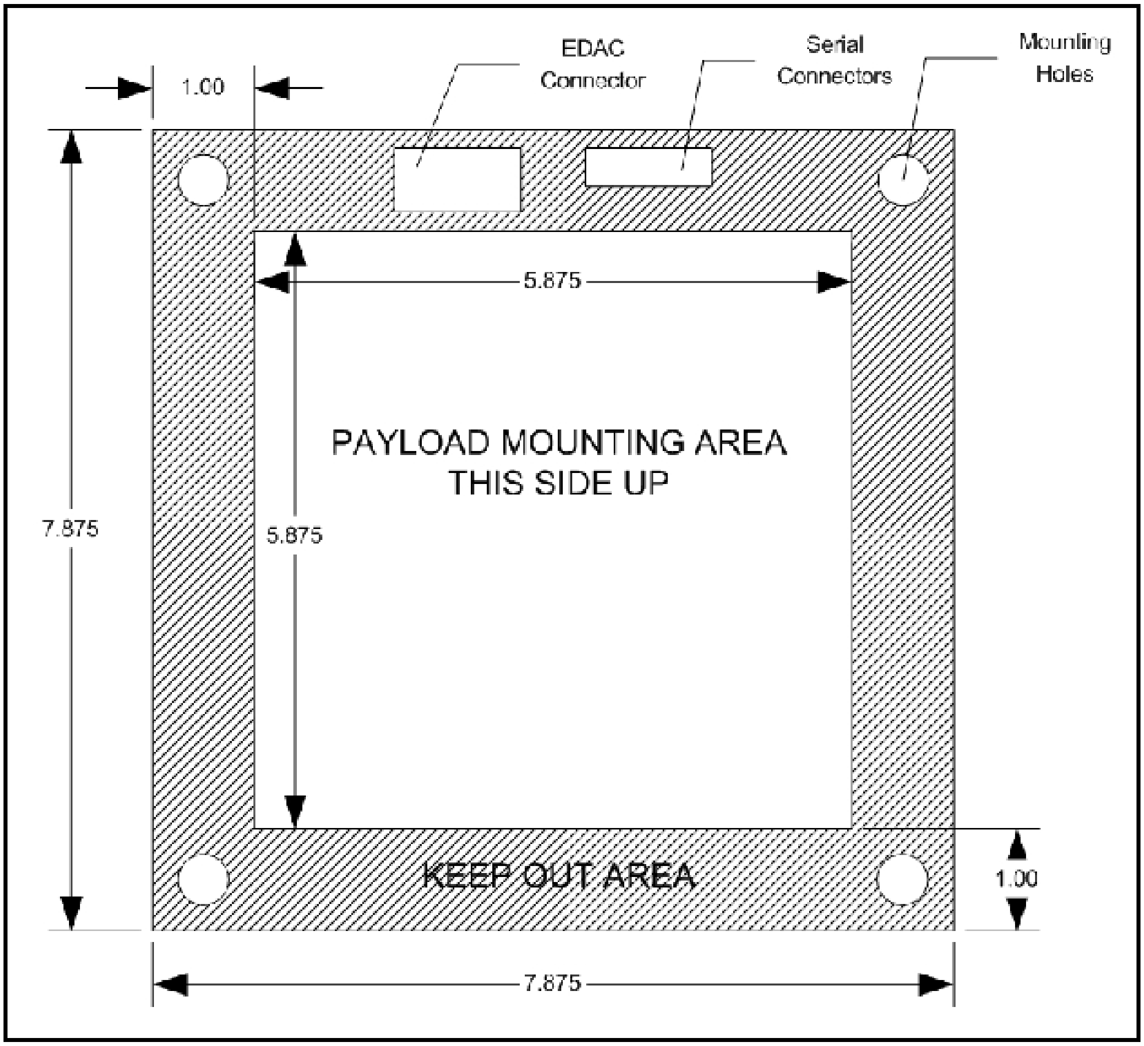

Fig 8 Mounting Plate for small payload (courtesy: HASP Version 02.17.09)

Desired location and orientation

The requested smaller payload should be oriented on the side away from any solar cells to avoid disparate solar thermal radiation. There should not be any obstacle for air circulation into payload. We also prefer that CosmoCam camera should be able to view our payload, particularly at the night time to watch the blinking of LED for the data collection. We would like the position of the payload on HASP to be the same as in the previous two flights. Fig. 9 shows our desired location of payload on HASP.

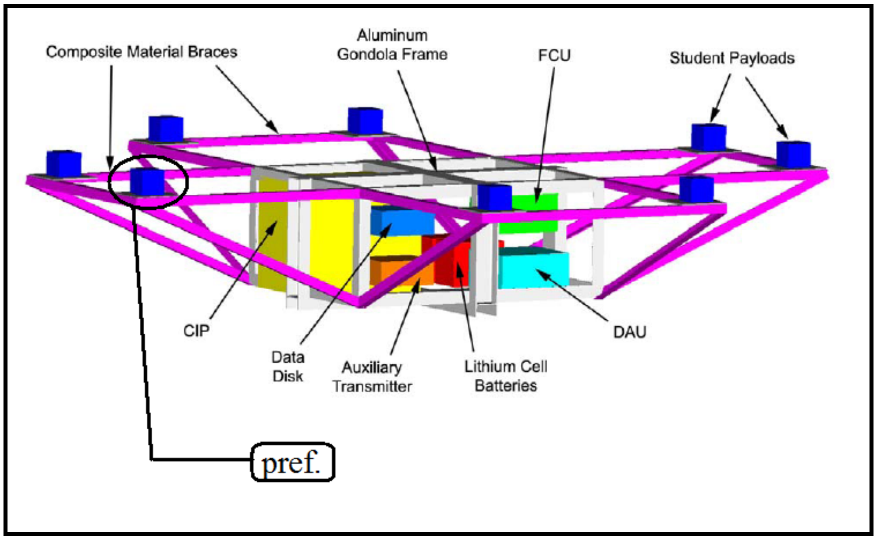

Fig. 9 – Proposed HASP Configuration (Guzik and Wefel, 2004)

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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. Mass of our HASP08 and 09 payloads was about 2.00 kg.

Payload Mass Budget

The mass budget is itemized below in Table 1.

Table 1 – Itemized Mass Budget

Item:	**Mass:**
Sensor arrays box (including RTD, fan, heater, box)	250g
Electronic circuits board	350g
Payload frame, screws and nuts	700g
Payload sides and thermal blanket	500g
Cables and any other items	200g
Total	**2000g**

The expected mass of payload will be less than the 3 kg limit for the smaller payloads.

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, utilizing such equations as shown in equation 1, heat transfer, showed the onboard sensor heater is adequate to keep the sensor at nominal conditions. An additional exploration of the effects of temperature on component integrity is ongoing, and part of the investigation. These initial estimations utilized the proposed materials for the walls, and a minimum temperature of -60°C and a general operating temperature of 15°C (found from altitude variation from 0 km to 36 km shown in the modified Fig. 8, altitude profile).

Equation 1 – Heat Transfer

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

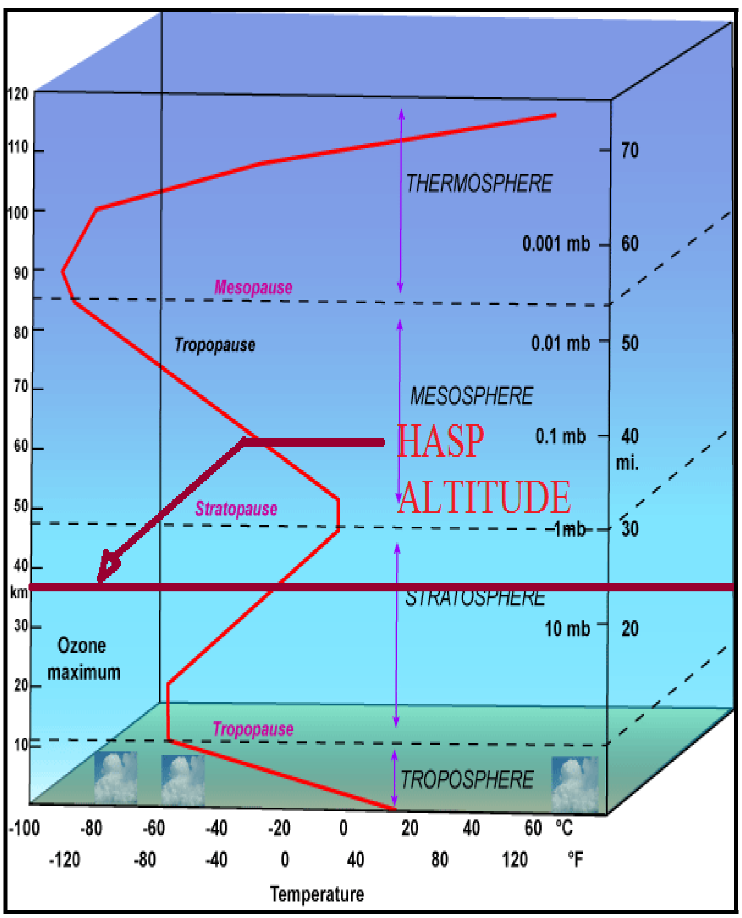
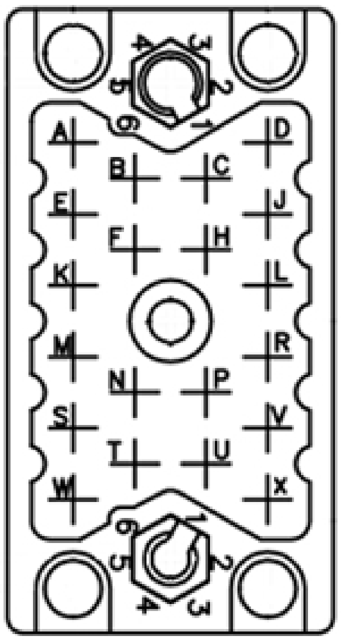


Fig. 10 – Modified Altitude Profile (Atkins, 2007)

As per the instructions, on the EDAC 516 power connector only pins A,B,C,D are wired to the payload as +30 VDC power supply and pins W,T,U,X are wired to payload as power ground to avoid failure to the power circuit or loss of payload. 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.



Function	EDAC Pins	Wire Color
+30 VDC	A,B,C,D	White with red stripe
Power Ground	W,T,U,X	White with black stripe
Analog 1	K	Blue
Analog 2	M	Red
Signal Return	L, R	Black
Discrete 1	F	Brown
Discrete 2	N	Green
Discrete 3	H	Red with white stripe
Discrete 4	P	Black with white stripe

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 master controller in the event that the telemetry link fails. The DB9 connecter is required 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.

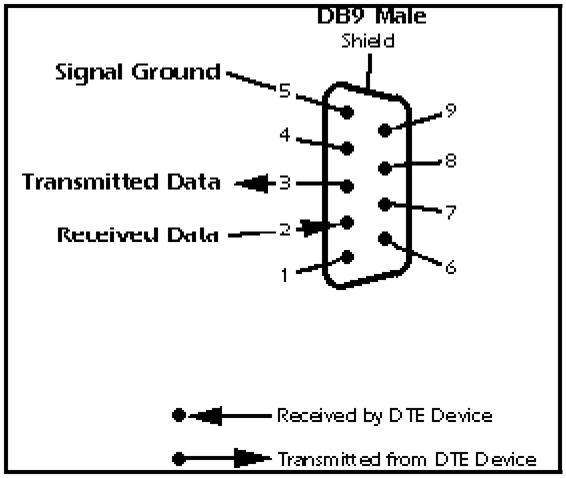


Fig. 12 DB9 pin diagram (courtesy: HASP manual)

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 and biological samples or parts 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 pf 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 sensors box from the payload. Test PCB with power and test sensor box
- Send sensors box 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 continue to utilize current funding of Florida Space Grant Consortium (FSGC) and will request FSGC for the additional funding for the travel and consumables.

References

(1) Solid-State Sensors Behavior in Reduced Pressure Environments Demonstration Using an Experimental Indium Tim Oxide Ozone Gas Sensors for Ozone Sounding Nathan Ambler, Ronald Fevig and Nirmal Patel, Proceedings of 59th International Astronautical Congress , Glasgow, (Sept 29-Oct 3, 2008), C2.I.17

(2) Hansford, Graeme M., et al. "A low cost instrument based on a solid state sensor for balloon-borne atmospheric O3 profile sounding." Journal Environmental Monitoring (2005): 158-162.

(3) Guzik, T. Gregory and John P. Wefel. "The High Altitude Student Platform (HASP) for Student-Built Payloads." 35th COSPAR Scientific Assembly. Houston, Texas, 2004. 1-8.

(4) HASP – Student Payload Interface Manual, Version 02.17.0 http://laspace.lsu.edu/hasp/documents/public/HASP_Interface_Manual_v21709.pdf

(5) Atkins, Noel. Survey of Meterology. 10 November 2007 http://apollo.lsc.vsc.edu/classes/met130/notes/chapter1/vert_temp_all.html